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D5.4 [Low iLUC land availability in Europe where camelina could be grown for the production of aviation fuel]

Main authors: Chris Harrison, Thomas Higginbottom, Simon Christie (MMU)

With contributions from: Manuel Sanchezblanco Palomera (SENASA), Yuri Herreras Yambanis (CCE) , Xavier Dommange (EADS-IW-F)

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Executive summary

An increasing awareness of the impact of fossil fuel usage on climate change has resulted in energy policies worldwide that support the use of renewable energy sources. Within the EU, biomass and the production of biofuel are seen to offer a viable option to reduce greenhouse gas emissions, whilst simultaneously improving fuel security, reducing dependency on imports, and potentially regenerating rural economies. However, the production of biofuels from EU grown feedstocks is ultimately limited by the availability of suitable land, and whilst it is expected that the demand for food within the EU for the next few decades will remain stable, the food first paradigm in tandem with the drive for an environmentally compatible agricultural industry under the auspices of the common agriculture policy, together with due consideration of the impact of land use change impose further constraints on land availability.

The ITAKA project has targeted camelina oil as a highly promising sustainable feedstock that can be cultivated within Europe in meaningful quantities and in a timely way that is also scalable. Both biofuel and feedstock sustainability have been assessed against the RSB EU RED Standard.

The low LUC model implemented within ITAKA has thus far targeted fallow land in arid or semi-arid regions of Spain, and to a lesser extent Romania. This model recognises that fallowing serves a valuable agronomic purpose such that not all fallow land is truly available, and has focused on the margin between minimum fallow and actual fallow. The scale up of this approach at EU level requires an assessment of potentially available low LUC land that might be targeted including fallow, abandoned and contaminated lands. On these lands camelina production can be considered to have no or low risk of LUC since it does not displace prior production.

The objective of this task has been to evaluate the availability of land that is compatible with the ITAKA low LUC model and is potentially accessible to scale up EU camelina feedstock production on a near to mid-term horizon.

For **fallow land**, the area across Europe has steadily decreased from 2002 when it was >11.6 Mha, to 2013 when it was >6.5 Mha, with many countries showing a high degree of variability. At country level, Spain has had the largest area of fallow land with >3 Mha consistently between 2002 and 2013. Poland, France and Romania were the only other EU member nations with >1 Mha of fallow land in at least one year between 2002 and 2013. Hence there are potentially large areas of fallow land within the EU and particularly within Spain that, subject to minimum fallow criteria, may be available for camelina cultivation. Furthermore, fallow land is considered a near term opportunity for scale up since it is probable that the necessary manpower, access to machinery, and infrastructure will be available.

For **abandoned land**, there is strong evidence for widespread abandonment of farmland in Southern and Eastern Europe. This abandonment generally falls into two categories: the collapse of the USSR in the early 1990's impacted Eastern Europe, and the decline of traditional livelihoods and the limited profitability of dryland farming in Southern Europe. However, recent evidence of re-cultivation on abandoned land in Eastern Europe implies that available land in this region may be rapidly declining, and the potential of any abandoned land must be assessed on a site-specific basis. Using published NUTS2[1] resolution statistical data to derive a regional and aggregated estimate of abandoned land would suggest that there might be 8.8 Mha of agricultural abandonment in the EU, whilst for the same calculation using similarly aggregated but national (NUTS0) resolution data would suggest this estimate is decrease to 6.8 Mha. However, land abandonment is a complex social, political and economic issue. The presence of large areas of abandoned land should be interpreted with caution; many areas may have environmental,

[1] NUTS2 refers to Nomenclature of Territorial Units for Statistics at resolution 2

economic or social limitation that may render them unsuitable for biofuel production. Planned development must take into account the site-specific conditions and limitations that may be present.

Contaminated land is recognized as a widespread infrastructure problem of varying intensity, significance and risk, which affects the whole of the EU. However, inventories for contaminated land are at a nascent stage of development within many EU member states or autonomous regions, with aspirational targets for the completion of land audits that stretch many years into the future. Current estimates of contaminated land are dependent upon expert judgement and so are inherently uncertain, and EU scale information is further fragmented due to a lack of common definition of land types between member states. Robust and ratified estimates for the area of contaminated land within the EU are unavailable. Information is fragmented and disordered. However, based on the limited data available it is likely that the area of contaminated land within the EU is significant and possibly in the order 5 to 10 Mha. To expect anything less after a 200 year legacy of intense industrialization and limited environmental legislation would seem unrealistic.

The second objective of this task has been to develop models that can be used to assess the production potential of camelina in the EU. These models have been developed in association with CCE and SENASA, and target the defined timeframe of 2017 – 2025. However, within this timeframe, addressable fallow is the only low LUC land category that land will possess the necessary manpower, access to machinery, and infrastructure to permit the development of viable camelina cultivation opportunities. Camelina cultivation on low LUC abandoned and contaminated land is predicted to be significantly more difficult to implement due to the lack of agronomic infrastructure, and so is envisaged as mid-term realisable opportunities. Modelling production potential for these land types is obstructed by several unknown parameters such as camelina productivity, barley to camelina productivity, localized aridity, CAP[2] compliance and penetration factors that will be location and site. Simple scaling by reference to surface area excludes the underlying uncertainties.

Using the first order assessment model and member state (NUTS0) resolution data, it is estimated that the EU camelina oil production potential is approximately 360,000 tonnes/year, which would corresponds to a HEFA biojet production potential of 234,000 tonnes/year . This estimate would be achievable within the defined timeframe, using just available fallow land, and is based upon realisable but conservative estimates of market penetration.

Whereas using the second order assessment model that is built on NUTS2 resolution data and is similarly limited to just fallow land, but which excludes high productivity land (>5 tonnes/ha), estimates the maximum EU camelina oil production potential to be approximately 1,104,000 tonnes/year. This corresponds to a maximum camelina biojet production potential of approximately of HEFA 717,000 tonnes/year. However, the estimates in this model do not include a penetration factor and therefore represents an upper limit.

Estimates of co-product volumes are also included. Some co-products are considered to be of economic value and are extracted from the field, whilst others considered of low economic value remain on the land as agricultural residues. These low value agricultural residues are nevertheless worth auditing because they have a high environmental value as soil conditioners. Camelina straw represents the greatest quantity of biomass, followed by husks and then seed. These residues represent a considerable reservoir of biomass. For example, if just 20% of the estimated 15.7 million tonnes of camelina straw were to be mobilized as biomass for power or heat generation each year, a considerable fraction of the embedded 50 Peta Joules of energy could be utilized[3].

[2] CAP refers to the Common Agricultural Policy

[3] Based on LHV for cellulose of 16 MJ/kg

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Abbreviations

CAP	Common Agricultural Policy
CCE	Camelina Company Espania
CLARINET	Contaminated Land Rehabilitation Network for Environmental Technologies
dLUC	direct Land Use Change
EEA	European Environment Agency
EU	European Union
FAO	Food and Agriculture Organization
FQD	Fuel Quality Directive
GEAC	Good Environmental and Agricultural Condition
GHG	Green House Gas
GIS	Geographical Information Systems
GLASOD	Global Assessment of Soil Degradation
ha	hectares
HEFA	Hydro-processed esters and fatty acids
H-ISD	Human-Induced Soil Degradation
iLUC	indirect Land Use Change
ISO	International Organization for Standardization
ISRIC	International Soil Reference and Information Centre
Kha	Kilo hectares
LUC	Land Use Change (the sum of direct & indirect effects)
LUCAS	Land Use and Coverage Area Survey
Mha	Million hectares
NUTS	Nomenclature of Territorial Units for Statistics
RED	Renewable Energy Directive
SENASA	Servicios y Estudios para la Navegacion Aerea y la Seguridad Aeronautica
UNEP	United Nations Environment Programme
UN FAO	United Nations Food and Agriculture Organization

1 Introduction

The use of land for the production of biofuel feedstocks within the EU has, and still is, the subject of considerable debate. Concerns about Land Use Change (LUC) and the perception that there is a limited resource of unused land on which biofuel feedstock cultivation might be exploited continues to be controversial, ill defined, and needs further investigation.

The ITAKA project[4] implements a sustainable approach to the production of aviation biofuel that has positive Green House Gas (GHG) lifecycle balance and generates attractive local economic incentives. This positive GHG balance addresses both direct emissions from the cultivation of feedstock, and the less tangible indirect GHG emissions from land use change. It is possible due to the progressive cultivation protocols that have been developed by CCE, and the selection of specific land types for feedstock production.

Within the context of the ITAKA low LUC agronomic models for the sustainable production of camelina, the low LUC land broadly consists of three acknowledged categories: fallow land, abandoned land and contaminated land. Of these three categories, fallow land offers the greatest near-term opportunity for expansion of feedstock production for the simple reasoning that 1) registered fallow land (through CAP) is easily identified, 2) the land is probably accessible with acceptable logical & transport constraints, and 3) agricultural labour and suitable machinery to work the land are probably available. In contrast, abandoned land within the EU is probably representative of a mid-term opportunity with less potential than fallow since 1) abandoned land is often situated in areas with relatively poor access and/or infrastructure, and 2) it has been abandoned due to a combination of economic but primarily social drivers and is therefore deficient in local labour or machinery. Hence, it is probable that regional development investments over time will be required to improve local infrastructure and develop the necessary resources before it is possible to realise the full potential of abandoned land. Whilst the use of contaminated land for biofuel feedstock production remains the most uncertain in terms of both timescale and potential. Contaminated land represents a highly complex situation since 1) it may involve multiple stakeholders including land owners, local industry, local authorities, environmental agencies as well as farmers, 2) it requires long term planning as well as site monitoring and reporting, and 3) the transference of contaminants to camelina must be evaluated on a site by site basis, and so the cultivation viability as well as the economics of production are unclear. Hence for biofuel feedstock production on contaminated land there would need to be a coordinated effort that apportions risk and benefits For example, local authorities would perceive bringing contaminated land back into useful production as a high value/low cost action with positive socio-economic impacts, whereas farmers may perceive this same action as high risk/low return.

The specific assessment of land suitability criteria including soil types, topography, rainfall, climatic condition, agriculture background, and regulatory specificities are difficult to identify explicitly as they are highly localized in nature. Consequently, a generalized broad scale analysis of suitability has been considered, whilst for the exploitation models developed to assess the potential opportunities for dry land replication of the ITAKA low LUC agronomic model, national and regional barley production data has been used as a proxy measurement with due recognition that in areas where production is high camelina will not be competitive.

The objective of this study is to identify land resources within the European territory where camelina might be grown for aviation biofuel feedstock production. However, within this assessment, identified land resources are constrained by their suitability and compatibility with the ITAKA low LUC agronomic models. Follow on questions such as how quickly might these land resources be mobilized into low LUC biofuel production are largely outside the scope of this task

[4] http://www.itaka-project.eu/default.aspx (Accessed October 2016).

as they are dependent upon the development and implementation of regional business models. Nevertheless where appropriate, due comment on the potential and constraints have been made.

The outcomes of this study will help quantify the potential land assets that could contribute to the aviation biofuel landscape through duplication of the ITAKA model, and subsequently, the potential volumes of sustainable camelina feedstock for the HEFA[5] biofuel pathway. This data will help inform decision-making and enable projections for future biofuel markets to be developed.

[5] ASTM D7566. http://www.astm.org/SNEWS/SO_2011/enright_so11.html (Accessed October 2016).

2 Background

The ambition of the ITAKA project has been to support the development of aviation biofuels in an economically, socially, and environmentally sustainable manner, improving the readiness of existing technology and infrastructures. In order to achieve this, ITAKA has targeted camelina oil as a highly promising sustainable feedstock that can be cultivated within Europe in meaningful quantities and in a timely way that is also scalable. Used cooking oil (UCO) has also been considered as an alternative feedstock, and both biofuel and feedstock sustainability have been assessed against the RSB EU RED[6] Standard. Nevertheless, the production of biofuel, the potential for land use change (LUC), and the possible conflict with food are controversial issues that raise a number of ethical concerns. Such concerns are plainly highlighted in other published studies (Di Lucia et al., 2012, von Witzke and Noleppa, 2014, Durham et al., 2012). To develop the context for this deliverable, a collation of background material has been included to frame the purpose of this research. This includes a description of current land use, direct and indirect land use change, and a brief description of the ITAKA low LUC model.

2.1 Land and soil

Although often interchanged land and soil are different entities that are intimately linked through feedback mechanisms. Soil influences the land cover and consequently land use, and in turn, land use impacts on soil. Where unsustainable land management practices lead to soil degradation and erosion, detrimental positive feedback mechanisms are likely to be established, resulting in sustained loss of production and ecosystem services. Such losses have notable consequences at a local, regional and global scale.

Soil is a complex bio-geochemical system composed of minerals, organic matter, water and air, the proportions of which reflect soil-forming factors and processes, such as geological parent material, climate and flora and soil fauna, active at a given site. Within Europe, soil resources show diversity and spatial variation from the poorly developed soils of the Mediterranean to the organic-rich soils of Northern Europe (EEA, 2010).

The most obvious function of soil to humanity is in the provision of biomass, food and raw materials. However, soil crucially acts to regulate the environment, filtering, transforming and storing substances such as water, nutrients and carbon (Bridges and Van Baren, 1997, EEA, 2010, Louwagie et al., 2011). Consequently, soil has a critical role to play in a wide range of eco-processes, for example, water management and through the storage and capture of carbon, climate change mitigation (EEA, 2010, Louwagie et al., 2011).

Policy makers and stakeholders are becoming increasingly aware of the importance of soils and concomitantly the vulnerability of soils to mismanagement and degradation. Comparison of estimates of formation rates of soils, 0.06 - 0.2mm per year (Wakatsuki and Rasyidin, 1992, Montgomery, 2007, EEA, 2010), with contemporary global erosion rates for cropland, 0.6 mm per year Montgomery (2007), suggest that an order of magnitude difference is likely to exist between erosion and production rates for agricultural soils. Therefore, at a human time-scale, it can be argued that soil is a non-renewable resource and as such must be carefully managed (Eswaran et al., 2001, Gobin et al., 2004). Fundamental to the management and control of soil loss processes is land use planning and land use change, which are coming under increasing scrutiny.

Given societies high dependence upon soil for the production of food and eco-services, it is perhaps surprising that at the European level, legislative policy for the protection of soil is uniquely missing (cf. Water Framework Directive 2000/60/EC or Air Quality Directive 2008/50/EC). Although

[6] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:190:0073:0074:EN:PDF

a draft EU framework directive[7] for the protection of soil was proposed in 2007, after several years of discussion with little progress, the European Commission withdrew the proposal in May 2014. Nevertheless, when withdrawing this proposal, the European Commission reaffirmed its commitment to the objective of protecting soil, and is currently examining other options on how to achieve this (http://ec.europa.eu/environment/soil/process_en.htm).

2.2 Current land use in the EU28

Since 2006, Eurostat has carried out the Land Use and Coverage Area Survey (LUCAS) every 3 years to identify changes in land use and cover in the European Union. These surveys are carried out in situ with field observations being made and registered from all over the EU. Ground survey data whilst to some extent subjective offer certain advantages over Geographical Information Systems (GIS), and both techniques are required to develop and understanding of land use and coverage.

The published LUCAS survey data from 2012 covers all the then 27 EU countries with observations at more than 270 000 points. The latest LUCAS survey captured between March and October 2015 surveys all EU28 Member States with observations at a total of 273 401 points.

The total land area of the EU27 was just over 4.3 million square kilometres (km²) in 2012. Woodland covered by far the largest proportion at 41.2%; around one quarter (24.7%) of the EU-27's land area was covered by cropland; while just under one fifth (19.5%) was covered by grassland. The remaining relatively small land area was proportioned as artificial areas covered 4.6%; shrubland at 4.0% and water areas as 3.2%; while the least common forms of cover were bareland at 1.5% and wetlands 1.4%. Formal definitions of the land use categories given to LUCAS surveyors are documented in Eurostat 2012.

Summary data for land use and coverage across the whole of the EU27 in the LUCAS 2012 survey are shown in Figure 1. LUCAS 2012 land use and coverage survey data for individual EU-27 countries is shown in Figure 2 and tabulated in Table 1.

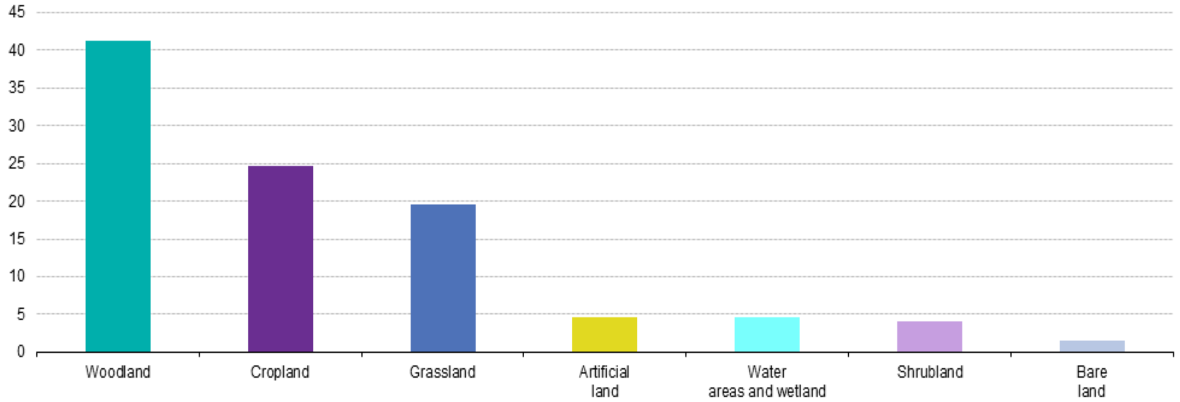


Figure 1. Summary data for the LUCAS 2012 land use and coverage survey for the whole of the EU-27. Source: Eurostat.

[7] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52002DC0179 (Accessed October 2016).

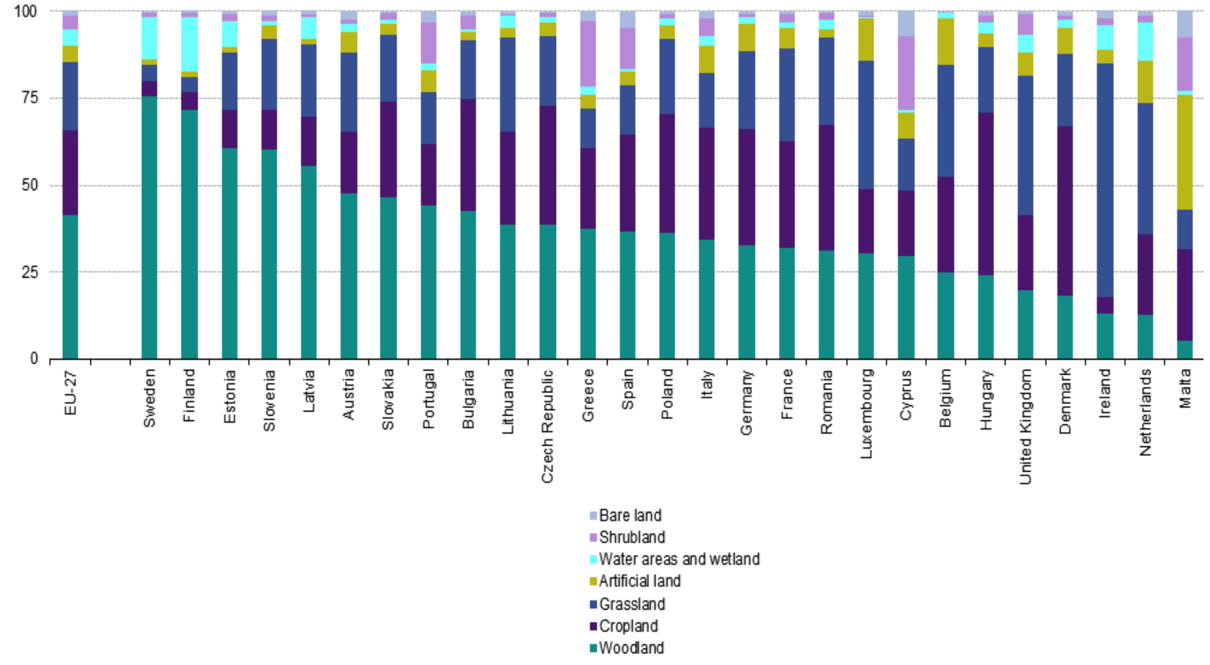


Figure 2. Lucas 2012 land use and coverage survey data individual EU-27 countries. Data for Croatia is unavailable. Source: Eurostat.

	Total area (km²)	Share of total area, by type of land cover (%)				
		Woodland and shrubland	Cropland	Grassland	Water and wetlands; bareland	Artificial
EU-27	4 306 585	45.2	24.7	19.5	6.1	4.6
Belgium	30 527	24.9	27.5	32.3	1.8	13.4
Bulgaria	110 900	46.5	32.2	16.8	2.2	2.3
Czech Republic	78 865	39.3	34.1	20.3	2.3	4.0
Denmark	42 895	19.6	48.5	21.1	3.7	7.1
Germany	357 134	33.8	33.1	22.5	2.9	7.7
Estonia	45 227	62.6	11.2	16.2	8.2	1.8
Ireland	69 797	15.2	4.7	67.1	9.2	3.9
Greece	131 957	56.5	23.2	11.4	5.2	3.8
Spain	498 511	48.4	28.0	13.9	5.7	3.9
France	543 965	34.3	30.6	26.9	2.4	5.8
Croatia	:	:	:	:	:	:
Italy	301 339	39.6	32.2	15.4	5.0	7.8
Cyprus	9 251	50.8	19.0	14.7	8.2	7.4
Latvia	64 562	56.4	14.0	21.0	7.0	1.6
Lithuania	65 300	38.9	26.7	27.2	4.5	2.6
Luxembourg	2 586	30.8	18.3	37.1	1.8	11.9
Hungary	93 024	26.3	46.9	18.8	4.3	3.7
Malta	316	20.3	26.6	11.4	8.9	32.9
Netherlands	41 542	14.4	23.1	38.0	12.3	12.2
Austria	83 879	48.7	17.7	22.9	4.9	5.8
Poland	312 679	37.2	34.1	21.6	3.1	3.9
Portugal	89 089	55.8	17.6	15.1	5.3	6.2
Romania	238 392	33.1	36.0	25.0	3.6	2.4
Slovenia	20 273	61.6	11.5	20.5	2.7	3.7
Slovakia	49 036	48.2	27.6	19.3	1.7	3.2
Finland	338 433	72.9	4.9	4.4	16.3	1.6
Sweden	438 576	76.6	4.3	4.6	12.7	1.8
United Kingdom	248 530	25.4	21.7	40.1	6.3	6.5

Table 1. Lucas 2012 land use and coverage survey data individual EU-27 countries. Data for Croatia is unavailable. Source: Eurostat.

2.3 Land use change and biofuels: Context and contentions

Over the past 15 year there has been increasing concern over the sustainability and long-term viability of energy supplies. The early 2000s were marked by considerable inflation in the price of oil, influenced in part by political instability in the Middle East. These issues, combined with increasing concerns over climate change and the need to limit CO_2 emissions has led to interest in the development and expansion of low-carbon and renewable energy sources.

Transitioning to low-carbon energy supplies is particularly difficult for fuel intensive industries that require high energy density fuels. This particularly affects the transport, and especially the aviation sector. Nevertheless, the aviation industry has established ambitious targets for both sustainability and low-carbon development. The EU has an overall target of a 60% reduction in transport sector CO_2 emissions by 2050, with aviation contributing by the usage of 40% low-carbon fuels (Mobility and Transport, 2011). In terms of emissions, reductions of 75% for CO_2, and 90% for NO_x per passenger km by 2050 relative to 2000, are envisaged (Advisory Council for Aviation Research and innovation in Europe, 2011).

The only viable low-carbon fuel option allowing heavy road transport and the aviation sectors to realise these ambitions is biofuels. Historically, biofuels were the primary fuel source for transport, through feedstock for animals. Since the mechanization of transport, biologically derived materials have been used to supplement conventional oil-based fuels. The majority of biofuels are either bio-ethanols, sourced from corn, sugar or starch, or biodiesels sourced from vegetable oils. Collectively bioethanol and biodiesel are classified as 1st generation biofuels. It is these first generation biofuels that have been the primary focus of policy, and controversy, over the past decade. More recently, there has been increased attention in 2nd generation fuels derived from inedible plant matter, such as woody biomass and crop residues.

Biomass energy, including power generation, has witnessed considerable growth since 2000, and now represents the largest renewable component of nearly every European nation. The uptake of biofuels for transport has seen a six-fold increase between 2000 and 2012. Yet bioenergy development has not been without controversy. The main criticisms of biomass energy relate to the land use changes induced by expanding fuel crop production. These controversies range from concerns over life cycle emissions, to the impacts on food production and prices. Although many of these issues are still debated, or heavily criticized, they have caused considerable public interest and facilitated tighter regulations on biofuel policies.

This section summarises current research on the interactions of fuel crop developments and associated land use change impacts. Key issues such as emissions and food security are reviewed, and the interplay with policy is discussed. Due the considerable differences in uptake and scale 1st and 2nd generation biofuels are discussed separately.

2.3.1 First Generation Biofuels

Growth and Trade. First generation biofuels (FGB) is an umbrella term to describe fuels produced from conventional food crops, normally referring to bioethanol and biodiesel. Bioethanol is generated by fermenting sugars extracted from crops such as corn, wheat or sugar cane. Biodiesel is extracted from oil crops such as palm, soy or rapeseed. Both of these are blended with conventional oil-based fuels, primarily petrol or diesel, prior to use. Between 2000 and 2012 the global consumption of 1st generation biofuels increased by 572 million barrels, a roughly six fold increase, see Figure 3 (Energy and Information Administration 2011). This growth was facilitated by a range of national and international policies. For example the EU's Renewable Energy Directive (RED) called for 10% of the transport sector's energy consumption to be renewable by 2020. To encourage sector growth the EU has implemented a considerable subsidy package, currently estimated at €8.4 billion annually **(International Energy Agency, 2014)**.

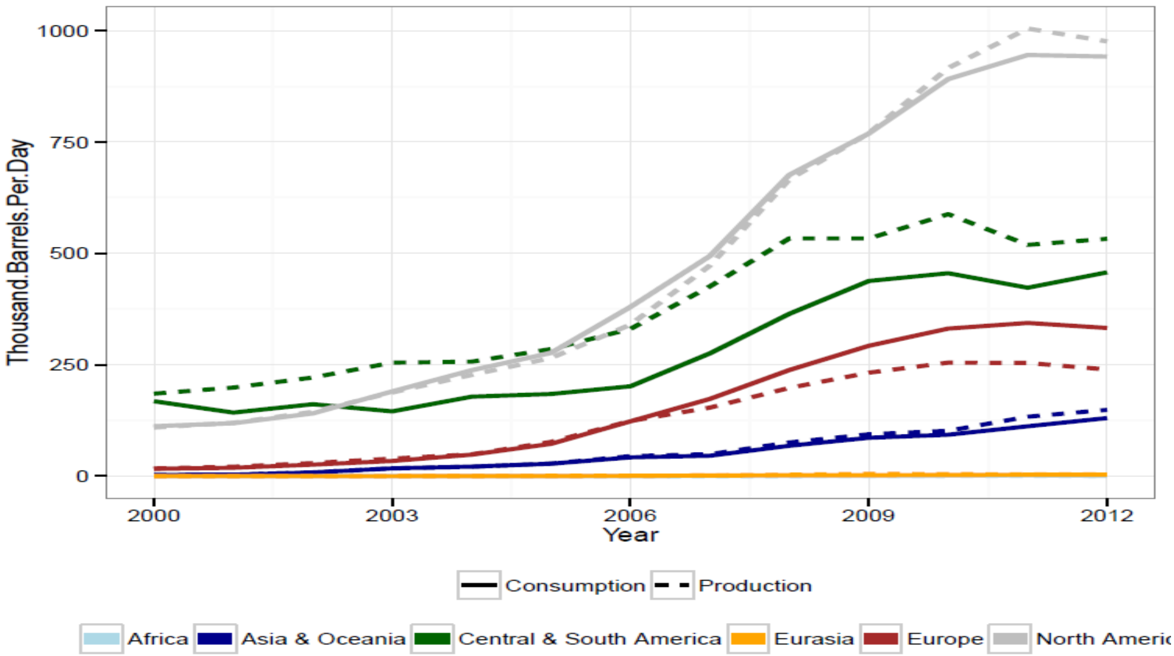


Figure 3. Continental Production and Consumption of biofuels, data Energy and Information Administration 2011).

In Europe, consumption of biofuels surpassed domestic production in 2006, and continued to diverge afterwards. This trade gap was filled by an increase in imports from nations with well-established agriculture sectors for the relevant fuel crops, in particular the United States, Brazil and additional tropical nations. The precise accounting of international trade for biofuels is highly convoluted and uncertain. This is due to the versatile usage of many fuel constituents; ethanol for example has a range of industrial application unrelated to fuel. Furthermore, variations in supply, demand, and taxation regimes result in large year-to-year fluctuations national-scale imports. Figure 4 shows the source of EU imports for bioethanol and biodiesel for 2009 and 2010. The high level of imports from the United States is mainly comprised of corn and soy-based products sourced from large-scale agriculture in Midwestern states. Due to a combination of government subsidies and low EU import tariffs it became possible for US companies to export bioethanol to the EU cheaper than it could be sold on the domestic market, a practice referred to as dumping. This advantage was further exacerbated by the practice of exporting blended biofuels a fuel product from the US (duty code HS 2207), but classifying imports to the EU as a chemical product (code E90) to qualify for lower import duty. To counter this practice and rebalance the market, in April 2012 this the EC classified all ethanol-gasoline blends containing 70% ethanol to 30% gasoline as denatured products, and thus unsuitable for human consumption (Regulation 211/2012). This forced ethanol-based fuels into a more severe fuel duty category increasing import tax from 6.5% to €102 per 1000 litres. These measures were extended in February 2014 by the announcement of official anti-dumping measures against the US, these added an additional duty of €63.3 per tonne. These changes initially led to a shift US exports, with a number of traders exporting to the EU via Norway to bypass the new measures. Modifications to the Anti-dumping measure halted this process in June 2014. Similar dumping accusations have occurred with soy-based oil originating in Argentina.

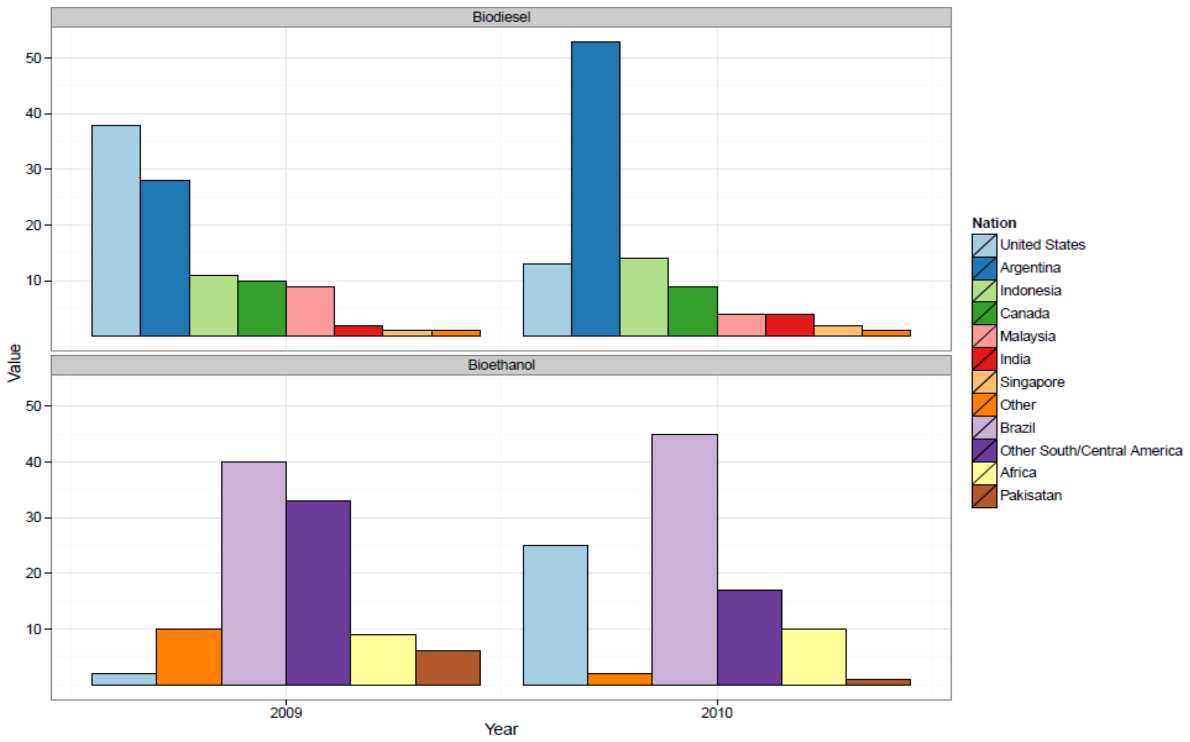


Figure 4. Origin of EU biofuel imports for 2009-2010.

Direct Land Use Change. First generation biofuels are produced from well-established agricultural crops, and require an infrastructure of refineries and distribution networks. Therefore the majority of developments have occurred in regions that already possessed these facilities, in particular Europe, mid-west America, and Brazil. Consequently, the direct land use change impacts of fuel crops have been focussed on farmland. Direct Land Use Change (dLUC) refers to the consequences that a development has on the in situ area that is converted to production. The primary upshot of converting farmland to fuel crops is that the land is no longer being devoted to food production. This has led to criticisms that biofuel expansion has impacted food prices and hindered poverty alleviation efforts.

In the late 2000s, food prices began to increase with major surges occurring in 2005-2008. Over this three year period, the International Monetary Fund (IMF) documented increases in a range of food price indices, including ~300% for corn, ~127% for wheat, ~170% for rice, ~192% in soybeans, and ~200% for palm oil. These increases followed a period of relative stability in food prices, and caused a re-examination of efforts to end malnutrition and the impacts of globalization. Increase in biofuel production and EU/USA consumption were proposed as (sometimes major) contributing factors. However, it should be cautioned that determining the influence of factors on food prices and increases, including any relationships with biofuels, is extremely controversial with a range of studies and NGOs expressing divergent opinions. This controversy is due to a number of statistical issues. Firstly, studies are heavily influence by the time examined, as longer studies observe greater cyclic pattern due to the "elasticity" of economics. Secondly, the criteria used for the categorization of food are also relevant, as animal feed and other by-products, such as oils, can influence results. Finally, the attribution of causation in any statistical study is a complicated task, requiring careful consideration and analysis. When studying global economic factors this issue is compounded by the dependency and correlation of many variables. For example, oil price is a major determinant of fertilizer prices, and of inflation in many nations. Furthermore, in many statistical models (regression analyses) the effects of variables cannot be separated when they are correlated, as models will use the strongest predictor, even when other factors may be influential.

The contribution of biofuel to global food prices is a controversial subject. One of the first widely circulated reports concern food price increases was a World Bank report Mitchell (2008). This report attributed 70% of food prices increases between 2002 and mid-2008 as biofuel induced (Mitchell, 2008). However, this was an internal document not intended for external circulation, and was later heavily criticized (Urbanchuk, 2008). In particular, Mitchell (2008) assumed that all of the increases in global corn production (2004-07) had gone to US bioethanol, U.S. Department of Agriculture (USDA) statistics clarify this be closer to 50%, a difference of 42.6 million tonnes (Urbanchuk, 2008). A review of studies modelling the biofuel impact on price fluctuations is given in von Witzke and Noleppa (2014) who compared a range of scientific articles and NGO policy documents.von Witzke and Noleppa (2014) concluded that there remains considerable uncertainty over the precise drivers of food prices, including the potential contribution of biofuel developments. However, peer-review studies generally proposed a lower contributions, <5%, than did NGOs who typically reported estimate over 25%. This discrepancy was attributed to NGOs being bias towards the upper envelope of model predictions, without reporting on the range or variability of potential scenarios. Nevertheless, the public debate over biofuels has been heavily bias by the assumption that there has been a major impact on food security, with a number of policy changes being implemented.

Indirect Land Use Change. In addition to direct LUC, indirect impacts also need to be considered. iLUC occurs when a development induces a land use change away from the initial location. This generally transpires through a "domino effect" whereby unintended side effects of a development incur a series of transitions. The main iLUC associated with fuel crops is increased deforestation in the Brazilian Amazon as a result of farmland conversion in Brazil and America to biofuels.

Brazil has been a major producer and consumer of bioethanol since the 1970s, with compulsory blending of ethanol and gasoline introduced as a response to the 1973 oil crisis. Thus, Brazil has a well-established biofuel industry regarded as one of the most sustainable, with a long record of exports to North America and the EU; (Figure 3 (Goldemberg, 2007)). The quantity of exports began to increase markedly in the early 2000s. This growth was seen as one cause of the escalation of deforestation in the Amazon basin that occur in the 2000-2005 period, see Figure 5 (Hansen et al., 2013). However, the impact of biofuel developments on Amazon deforestation originated not from the direct conversion of forest to plantations for fuel stock, but rather indirectly induced land use changes. As US demand for corn-based ethanol increased in the 2000s a large number of American farmers switched from planting soy, primarily used for animal feed, to corn (Laurance, 2007). In the same period Argentina, a major global producer of soybeans and beef entered a prolonged recession leading to a collapse in exports. These factors combined to escalate the global prices of beef and soy (Figure 6). This led to the conversion of a large number of Brazilian cattle ranches to soy plantations, with the displaced pastures regained by advancing the deforestation frontier, see Figure 7 (Laurance, 2007, Barona et al., 2010, Macedo et al., 2012). This process was most apparent in the 2000 to 2005 period, when deforestation in Brazil peaked at 41,000 km^2 per year, Figure 5 (Hansen et al., 2013). The epicentre of both soy-pasture displacement and deforestation, was the frontier state of Matto Grosso. In the years 2000-2006 the area of soy cropland doubled to 6 million ha, of which 74% was on former pastures with 26% on fresh deforestation (Macedo et al., 2012). Further indirect land use changes were caused by increasing national and international increases in sugar and bioethanol prices. Pastures in southern Brazil were converted to sugar cane plantation to maximise profits, with low land prices in the Amazon frontier encouraging deforestation for new rangelands.

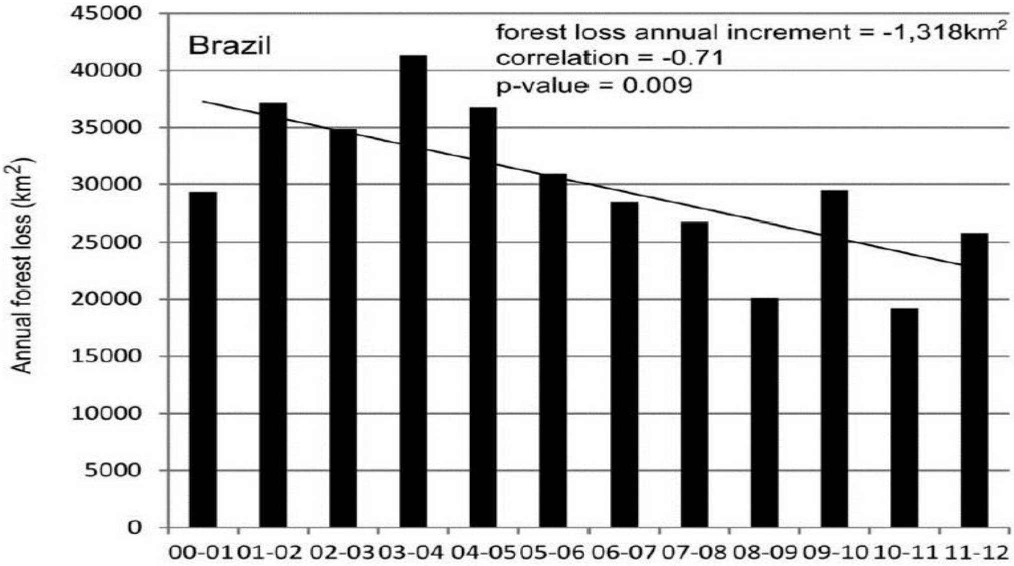


Figure 5. Annual forest loss total for Brazil from 2000 to 2012, modified from (Hansen et al. 2013).

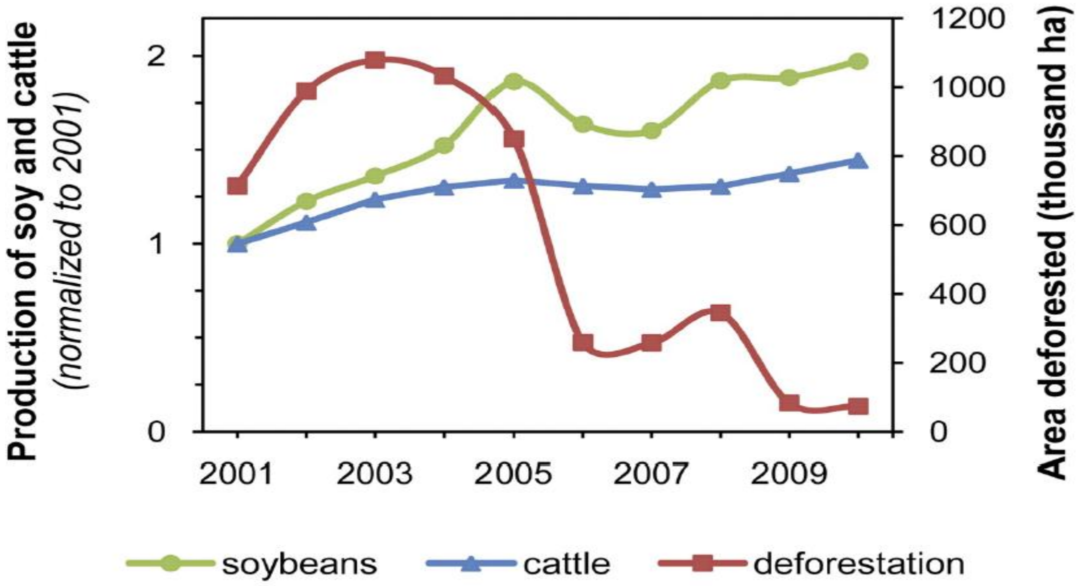


Figure 6. Deforestation, tons of soy produced, and number of heads of cattle produced in Mato Grosso, Brazil. From Barona et al (2009).

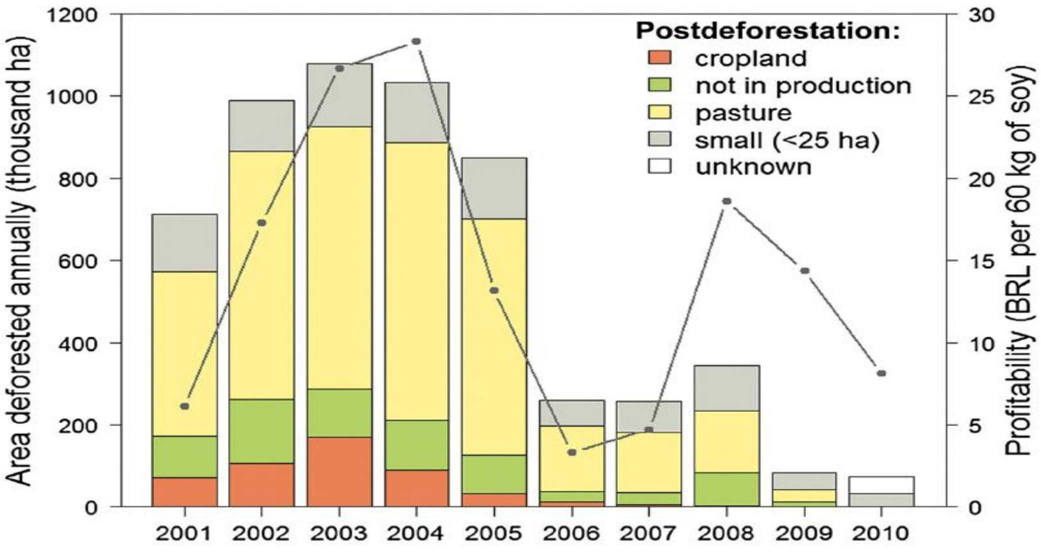


Figure 7. Post-deforestation land uses in Matto Grosso and Soy Profitability, from (Macedo et al. 2012).

The emergence of evidence for indirect land use changes (iLUC) forced a re-analysis of the carbon benefit returned by biofuel expansion. The premise of biofuels as a renewable fuel source is that CO_2 emitted during combustion is reabsorbed by photosynthesis, leading to a balanced carbon cycle, minus emissions incurred from production and processing. The time taken for a development to become neutral, or beneficial, is referred to as the "carbon debt" this is calculated by quantifying the emissions inured by the LUC divided by the annual emissions prevented. The carbon debt induced by the direct conversion of land for plantations had highlighted that it was counter intuitive to convert high-biomass ecosystems, in particular forests and savannah, to plantations (Fargione et al., 2008). However, the emergence of indirect land use changes proved more complex to model, as impacts may occur on separate continents following variable time lags. Plevin et al. (2010) and Searchinger et al. (2008) estimated that increasing US corn ethanol production to the 102 billion litres Congressional target would incur a doubling of CO_2 emission for 30 years, with carbon neutrality not achieved for 167 years. Even when the highly productive Brazilian bioethanol industry is considered meeting government targets by 2020 would sustain deforestation of 121,970 km^2 in the Amazon, culminating in a 250 year carbon debt (Lapola et al., 2010). iLUC effects are exacerbated as US and European croplands are typically far more productive than replacements in other nations, leading to either an expansion of farmed areas or loss of production. This will simultaneously increase the use of fertilizers, nitrous oxide emission and transport (Plevin et al., 2010).

2.3.2 Second Generation Biofuels

Whereas FGB have been produced in large quantities for a number of years, increasing focus is being directed at the production of Second Generation Biofuels (SGB). SGB are produced from the processing of non-edible plant biomass, such as woody or lignocellulosic components. This enables a wider range of sources to be utilized, for example crop residues or waste products. The advantages of SGB are that there is greater potential in both the amount of energy that can be extracted, and a large array of candidate fuel crops.

Compared to conventional biofuels SGB are a recent development with limited commercial uptake beyond research and development. There is therefore very limited data on production and consumption available. This restricts the analysis of the land-use changes that may be induced by the development of SGB. The sub-sections below summarise a number of scenarios by which 2nd generation biofuels may be cultivated, and the associated potential LUC impacts.

2.3.2.1 Crop Waste Products

Material residues that remain after the harvest of crops have the potential to be used as biofuel sources. Components such as stalks, stems and seed-pods can have high levels of lignocellulosic biomass, particularly for crop such as maize. Generating fuels from these resources will have a reduced iLUC affect as the primary function of the land, i.e. food production, is preserved. The main iLUC impact from waste product use is likely to be increased imports of animal feedstock. The intensity of this issue will vary with local practices and economics. Care is also required when removing residues from fields. In many localities, stubble is a key land management resource that provides perennial vegetation cover reducing erosion and preserving soil carbon.

2.3.2.2 Rotational Farming Cycles

Many regions, particularly dryland and Mediterranean localities, employ rotational farming practices. This typically involves the leaving a field on a 1 in 4-5 year cycle. This purpose of fallowing is to allow soil properties such as nitrogen and water to recover, maintaining the fertility of the soil. Fuels crops that encourage nitrogen fixation and water retention could therefore confer duel benefits of preserving fertility and offering an additional income. This option should have no land use change impacts as the current land use is not altered. There could be unintended impacts if the prices offered incentives additional fallowing (and fuel crop production) over food crops.

2.3.2.3 Development of Marginal Lands

Marginal lands are potentially productive areas that are either not in use, or marginally yielding. This covers area of abandoned agriculture and contaminated land. These lands are seen as a potential solution to land use conflicts, as food producing agriculture and native habitats can be preserved, whilst increase fuel crop yields. Indirect land use changes from these categories should be negligible as the land is by definition marginally productive at best. The main consideration of development in marginal lands is the interruption of ecological succession processes that would have resulted in high-values ecosystems, if undisturbed.

2.3.3 Summary

In summary, second generation biofuels present a challenge for development planning. In order to be environmentally friendly and avoid the criticisms of first generation biofuels careful planning of developments must be undertaken. Consideration must be given to climate, soils, direct and indirect land use change, and social issues. The following sections of this report will investigate these issues and present an overview of land suitable for second generation biofuels within the EU, using camelina as a candidate crop. Although Camelina is an edible crop, it is widely accepted to be a second-generation biofuel feedstock due to low use as a food stock.

2.4 ITAKA low iLUC model

If the production of biofuel feedstock can be demonstrated to cause little or no displacement of existing provisioning services, including food, feed, fuel and fibre, then it could be argued that it would not trigger a demand-supply imbalance, and the production of the biofuel would cause no upward pressure on land-based commodities and would not drive the process of land use conversion. It can thus be said to have no or low risk of causing LUC.

An extensive analysis of iLUC pertaining to the ITAKA agronomic model is given in the sister deliverable D5.6, Indirect Land Use Change Assessment Report. This assessment takes into account the land use requirements for camelina production (including considerations on yields, agricultural model, potential for production on contaminated land, etc.), as well as the different uses of co-products. The analysis is not numerical in nature, as the goal is not to calculate iLUC factors, it is a qualitative assessment that focuses on the impacts of camelina production practices and choices.

The ITAKA project targeted camelina oil as a highly promising sustainable feedstock that can be cultivated within Europe in meaningful quantities and in a timely way that is also scalable. Primarily, camelina cultivation has been in the arid or semi-arid regions of Spain and to a lesser extent Romania. Both biofuel and feedstock sustainability have been assessed against the RSB EU RED Standard[8].

In Spain, camelina is being introduced into cereal rotation schemes within regions of low productivity where leguminous crops and other oilseed crops have very low yields. Under these circumstances, camelina is proving to be a hardy crop, requiring few inputs and with the potential to reduce the level of fallowing and increase overall productivity. In addition, the camelina meal produced from the pressed seed could result in a net reduction in animal feed imports and have a net iLUC reducing effect. This is in direct contrast to the impact in more fertile and/or less arid regions in Spain, where camelina would appear to occupy a role similar to that of rapeseed oil, and although camelina is more sturdy, potentially having larger yields on low-rainfall years, yields are generally lower than that of rapeseed, In these circumstances camelina becomes competitive with food or feed crops, and cannot be said to have net iLUC benefits or low LUC risk. Consequently, the micro-level processes that may lead to higher level LUC through displacement dynamics depend on the specific context and should be assessed case-specifically.

The low LUC model progressed through ITAKA has thus far targeted fallow land in arid or semi-arid regions, whilst also recognising that fallowing serves a valuable purpose such that not all fallow land is truly available, it has focused on the margin between minimum fallow and actual fallow. The scale up of this approach at EU level requires an assessment of potentially available low LUC land that might be targeted including fallow, abandoned and contaminated lands. On these lands camelina production can be considered to have no or low risk of LUC since it does not displace prior production, or if production of food, feed or fibre is not possible due to contamination concerns. Although in heavily contaminated soils, attention should also be paid to potential re-exposure of humans, animals and wildlife to contaminants through the use of these feedstocks.

[8] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:190:0073:0074:EN:PDF (Accessed October 2016).

3 Broad scale assessment of land suitable for the cultivation of camelina

The sustainable development of biofuel resources requires the strategic usage of land resources, to ensure that food production and biodiversity are preserved. The availability of land for biofuel production is determined by two levels of constraint; Firstly, the land must be appropriate for cultivation, both climatically and pedologically. Secondly, the area must belong to an indirect land use change (iLUC) category; this encompasses land where conversion to biofuel production does negatively affect upon the food production or biodiversity such as fallow or abandoned land.

This section will present data on the climate and soil characteristics of Europe, and identify areas where the cultivation of camelina is possible. This will serve as a precursor to the identification of low land-use change potential areas. Firstly, the bio-climate and geographic regions of Europe are summarized, presenting a brief overview of conditions on the continent. Secondly, specific variables relevant to crop cultivation are assessed and ranked according to suitability for camelina production.

3.1 Climatic and biogeographic regions of Europe

The European continent contains a variety of climatic and biogeographic regions; shown in Figure 8 and Figure 9. In general, Northern and Western Europe possess an oceanic climate due to proximity to the Atlantic Ocean and exposure to prevailing westerlies. Resulting in year round precipitation and cloudiness, with moderate summer temperatures and relatively mild winters. In contrast, Southern Europe displays a Mediterranean climate with warm dry summers and mild, wet, frost-free winters. Continental Europe displays a midway between the north and south, with a strong contrast between warm summers and cold snowy winters. Alpine climate are limited to major mountain ranges such as the Alps, Carpathians and Pyrenees.

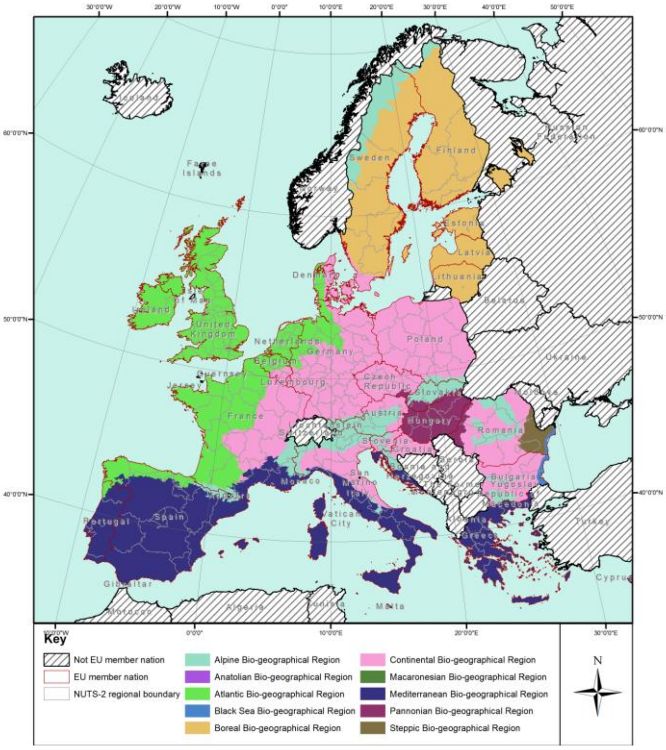


Figure 8 Biogeographic regions of Europe. Data sources from the University of Edinburgh (Metzger et al, 2002).

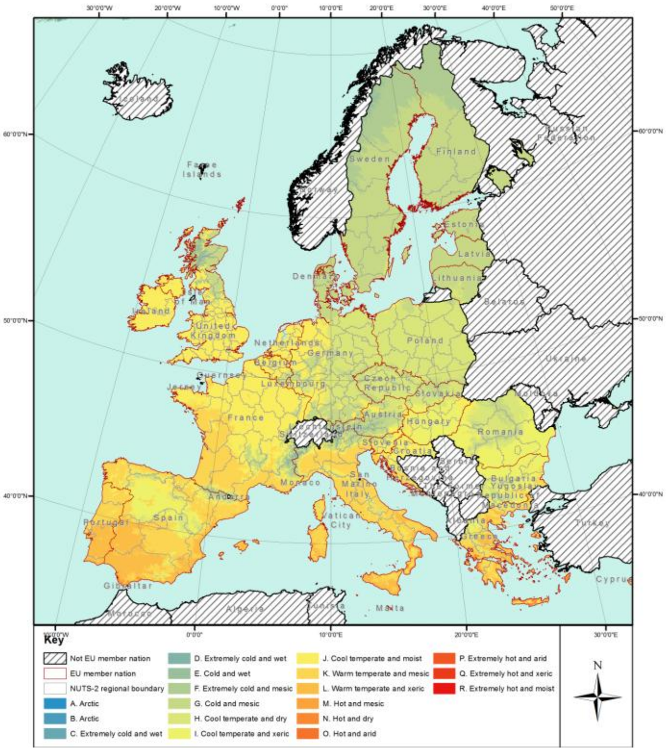


Figure 9. Climatic zones of Europe. Data sourced from the EEA[9].

[9] http://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3 (Accessed October 2016).

3.2 Agronomic Variables

The productivity and success of arable crops is influence by a variety of environmental factors. The climate and ecological characteristics of an area can be used to pre-emptively determine suitability for a particular crop. Camelina is no exception to this, and productivity is determined by both climate and soil conditions.

In this section datasets related to climate and soil are summarized to explore the suitability of Europe for camelina production. Figures are presented that display the raw data and the overall suitability for camelina production.

3.2.1 Datasets

3.2.1.1 Precipitation: Europe

European-level data was extraction from the Global Precipitation Climate Centre (GPCC) Version 7 Precipitation Product. This is a 110-year (1901-2010) record of global land rainfall at 0.5-degree resolution. The GPCC collates gauge data from 75,000 stations worldwide, with stations requiring a minimum time-series of 10 year to qualify for inclusion. The data is provided as monthly layers of total precipitation.

3.2.1.2 Precipitation: Spain

High-resolution rainfall data for Spain was obtained from the Spain 02.V4 precipitation product generated by the University of Santander and Spanish Meteorology Agency. This data is generated through interpolation of ~ 2,500-rainfall station across Spain and the Balearic Islands. Monthly and daily total rainfall layers are generated for the 1971-2010.

3.2.1.3 Soil

Pedological data covering topsoil organic matter, topsoil texture, topsoil pH, and soil depth was obtained from the European Food Safety Authority (EFSA) Spatial dataset version 1.1 (Hiederer, 2012). The EFSA Spatial Dataset is a collection of spatial datasets covering factors of interest to agricultural productivity (climate, soils crops, land use), provided in a standardized resolution (~1km), projection and extent. Soil components of the ESFA are extracted from the Harmonized World Soil Database (HWSD) Version 1.1 (Nachtergaele et al., 2008), which for Eurasia is in turn extracted from the European Soil Database (ESDB) (Jones et al., 2005). The ESDB is a standardized collation of regional and national soil surveys and sampling archives (Bullock et al., 1999). As such, there is considerable inconsistency in both the number and resolution of surveys undertaken by the contributing nation states (Figure 10 and Figure 11). It should also be cautioned that whereas many smaller European nations may have a high number of surveys, these can be several decades old and thus in need of updating for modern classification systems. Given the discrepancies in sampling coverage and methodologies the ESDB is produced in Soil Mapping Units (SMU's) to represent to dominant soil properties for the area.

Note: Soil Depth is not provided by the EFSA dataset, was so obtained from the ESDB and standardized to the EFSA layers.

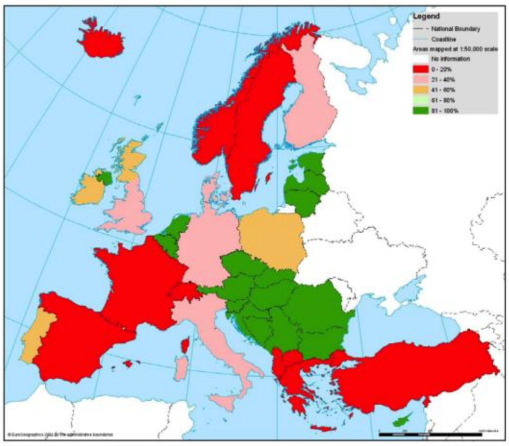


Figure 10. Availability of detailed soil surveys at 1:50,000 or 1:25,000 scale (From Jones et al., 2005).

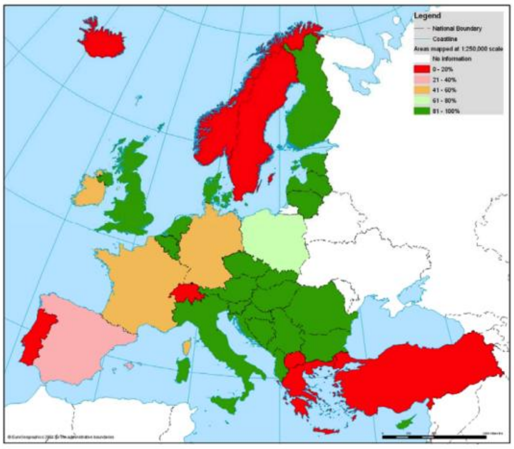


Figure 11. Availability of 1:250,000 scale soil surveys in the EU (From Jones et al., 2005).

3.2.1.4 Depth to Water Table

There is currently no EU-wide dataset detailing depth to the water table. Therefore data was obtained from Fan et al. (2013). The authors collated a wide range of scientific, government, and commercial water table depth records to establish the most comprehensive global database of ground water. To generate global coverage, a hydrological model was used to estimate vertically integrated lateral groundwater movement at 30-arc seconds (~1km) resolution. For Western Europe 78,180 records were identified, locations shown in Figure 12.

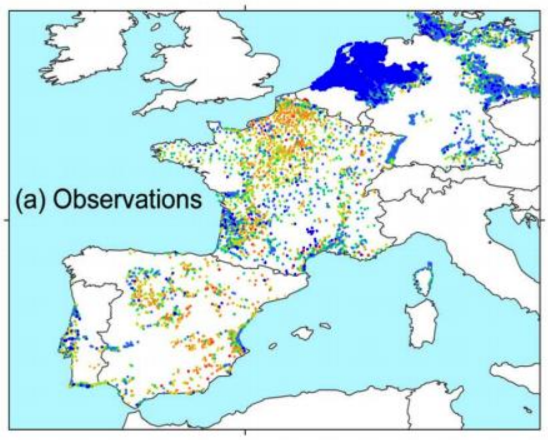


Figure 12. Location of Depth to Water Table Records, for western Europe, collated by Fan et al., (2013).

3.2.1.5 Suitability criteria and classification

To rank the suitability of these parameters the various layers were classified according to information supplied by Camelina Company España (Table 2). Variables were classified into three suitability categories with associated scores; A/3- Good), B/2 Medium, and C/1-Acceptable.

Table 2. Suitability Classifications for camelina growth, A-Good, B- Medium, C-Acceptable.

	A	B	C
Soil pH range	7 to 8	6 to 8	5.5 to 8.5
Planting soil temperature (C)	*4*	*4*	*4*
Soil depth*[1]	> 1m	0,5 - 1m	<0,5m
Depth to water table	0,25-5m	5-20m	>20m
Organic matter in the soil	>2%	1-2%	<1%
Soil texture*[2]	Loam soil	Loam sandy	Clayey

Notes

*1 soil depth data is classified by the EFSA into the following categories: A-Very Deep (>120cm), Deep (80-120cm),B- Moderate (40-80cm), C- Shallow (<40cm), and non-soil.

*2 Soil Texture Is classified by the EFSA into the following grain size categories: Very Fine(C), Fine(B), Medium Fine(NA), Medium(A), Coarse(NA), and peat.

All precipitation datasets were aggregated into annual values, and the mean annual rainfall for the respective periods was calculated. To quantify the “climate risk” and uncertainty within the precipitation averages a number of metric were calculated. These metrics include standard deviation, relative standard deviation (percentage), number of years rainfall levels were good, moderate or acceptable.

Table 3. Suitability of annual rainfall levels.

Suitability	Rainfall (mm/year)
Insufficient	0-100
Marginal	100-150
Acceptable	150-300
Moderate	300-400
Good	400-500
Excessive	500+

3.2.2 Results

3.2.2.1 Pedology and Hydrology

The classified soil/hydrology variables were aggregated into a single suitability layer, shown in Figure 13. This highlights the suitability of EU soils for camelina production. Notably, few areas were classified as widespread low potential suitability. Only Finland, Scotland and Portugal featured national scale unsuitability, due to acidic soils possessing low organic matter. Areas with the highest suitability are generally found in Eastern and Mediterranean Europe, with Spain, Greece, Estonia and Lithuania demonstrating highly suitable soil/hydrology.

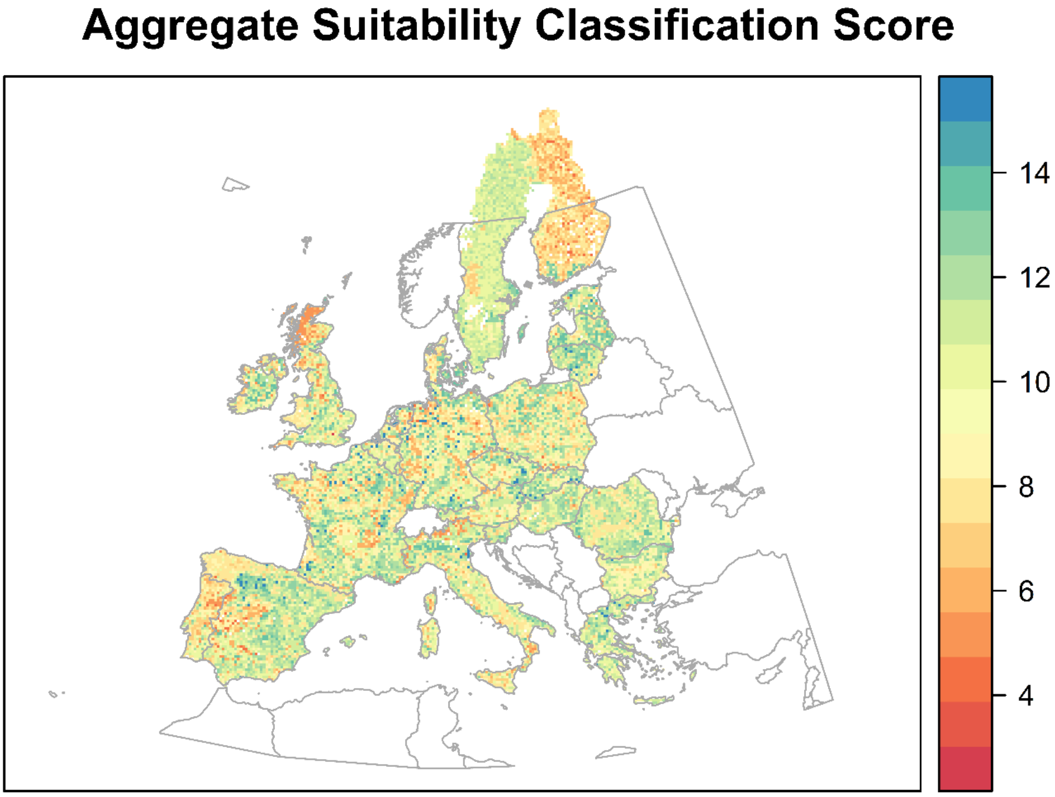


Figure 13. Aggregate Score for soil/hydrology suitability Generated as the sum-total of the soil and hydrological variable suitability classification

3.2.2.2 Rainfall Europe

Assessment of the GPCC data highlights that the majority of Europe would be classified as excessive rainfall (>500 mm/year). Areas receiving good and acceptable mean annual rainfall (300-400 / 400-500 mm/year) can be found in central and eastern Spain, on the Black Sea coast and in Northern Scandinavia. The climatic risk is quantified by the standard deviation (absolute and relative), and by summing the number of year to meet the rainfall thresholds. This analysis identifies Spain and the Blank Sea cost as the most frequently receiving good levels of annual rainfall. However, these areas demonstrate the highest relative standard deviations, and are more likely to exhibit marginal suitability.

3.2.2.3 Spain

Analysis of the high-resolution Spain_02 precipitation data generally agreed with the coarse-scale GPCC product. Eastern and central regions of Spain demonstrated good and moderate levels of rainfall, with the northern and southern coastal areas being excessive in mean annual precipitation. The southern sections of high suitability exhibited higher absolute and relative standard deviations. Furthermore, central and northern areas had higher counts of good and moderate rainfall years, although these differences are minor.

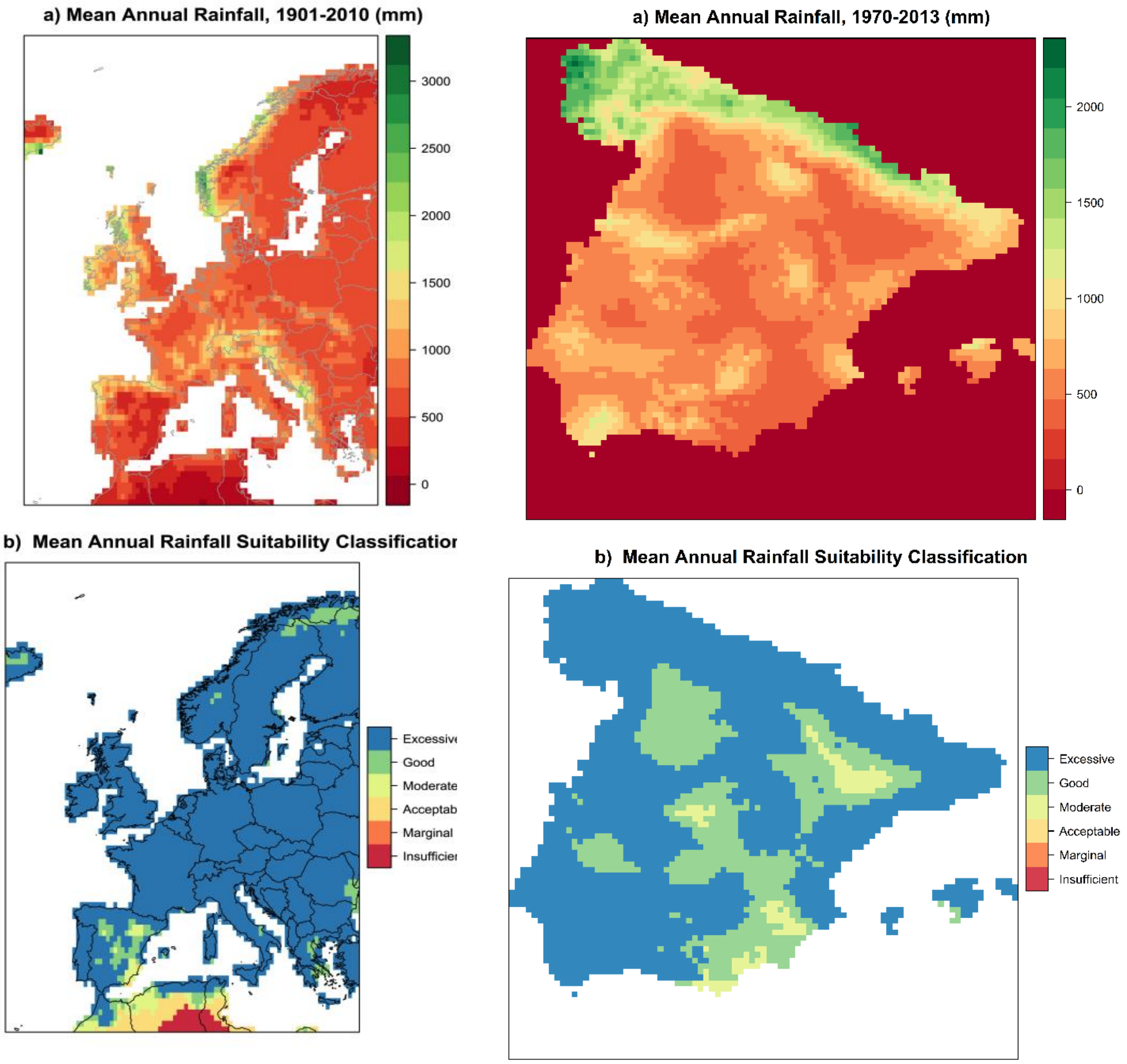


Figure 14. Analysis of rainfall data for Europe and Spain: annual mean.

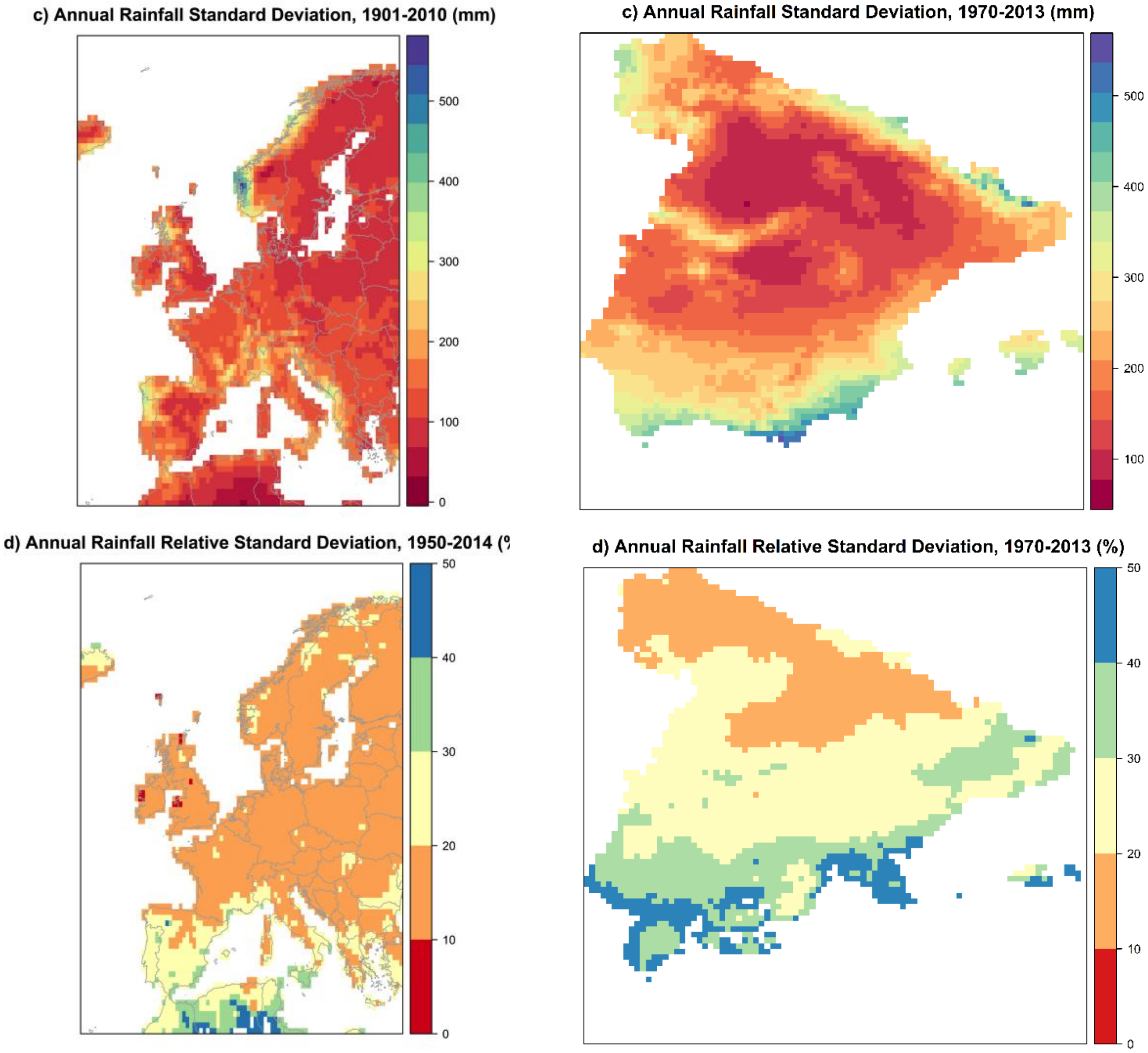


Figure 14. Analysis of rainfall data for Europe and Spain: standard deviation from annual mean.

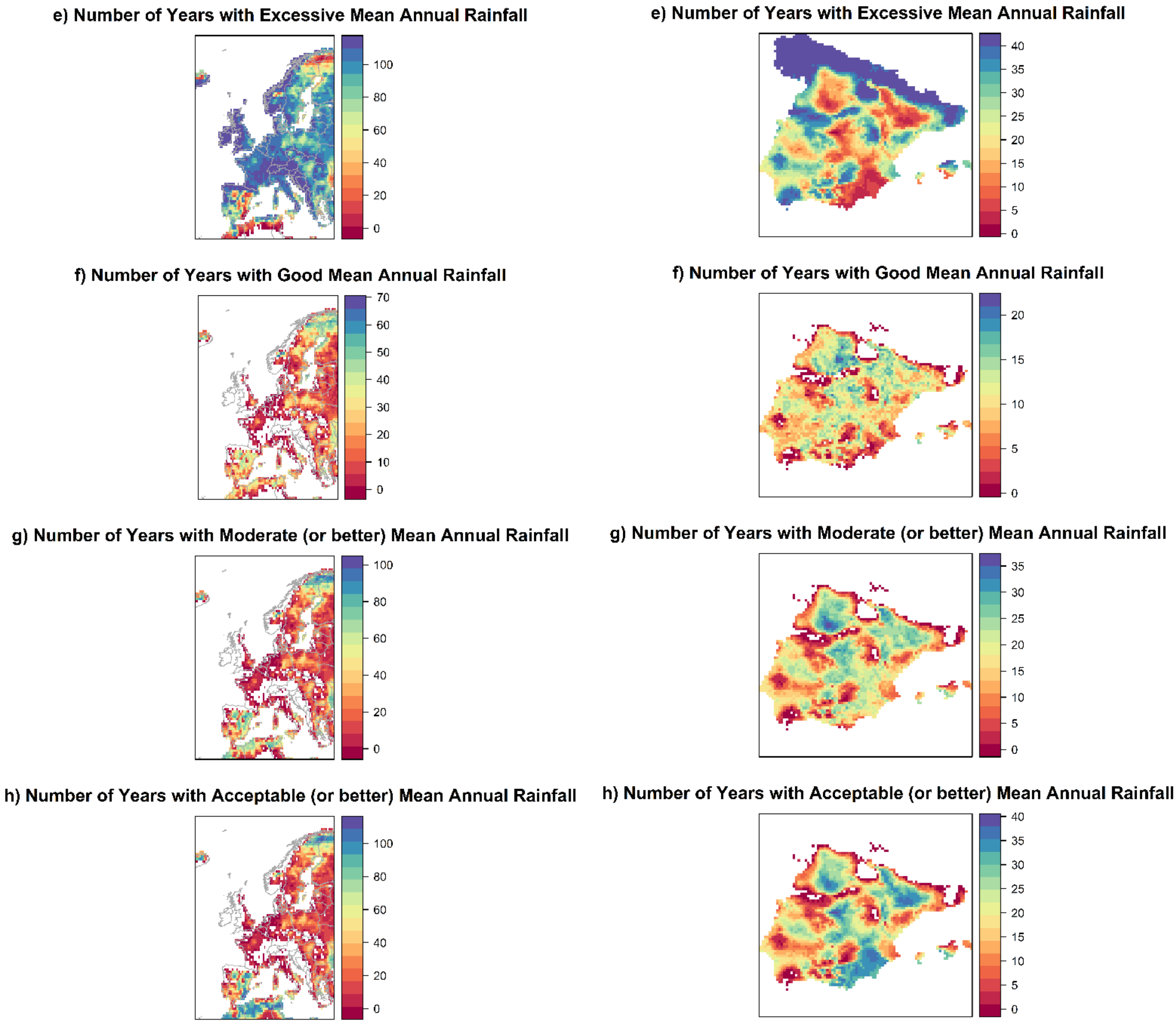
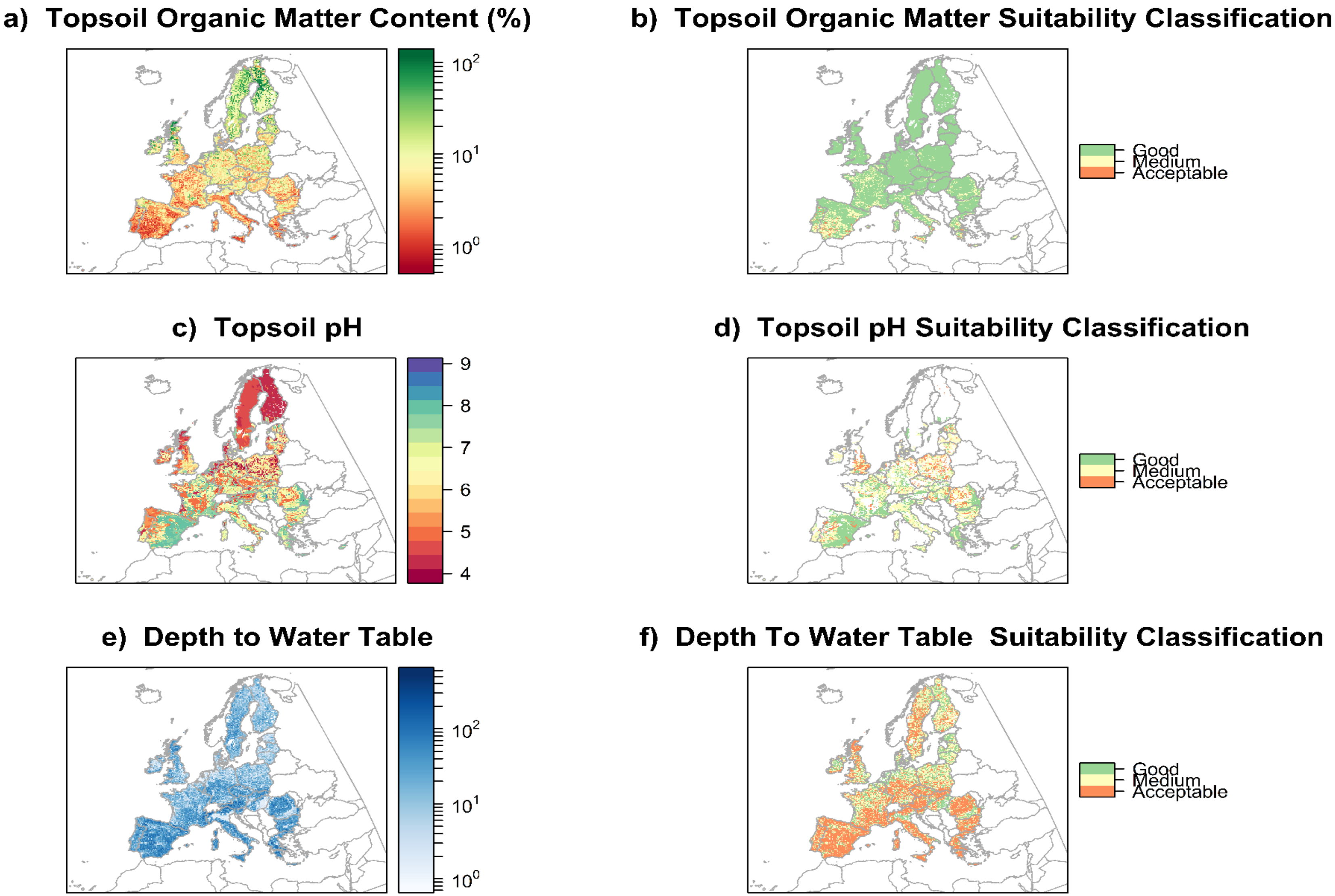


Figure 14. Analysis of rainfall data for Europe and Spain: variability.


a) Topsoil Organic Matter Content (%)
10^2
10^1
10^0
b) Topsoil Organic Matter Suitability Classification
Good
Medium
Acceptable
c) Topsoil pH
9
8
7
6
5
4
d) Topsoil pH Suitability Classification
Good
Medium
Acceptable
e) Depth to Water Table
10^2
10^1
10^0
f) Depth To Water Table Suitability Classification
Good
Medium
Acceptable

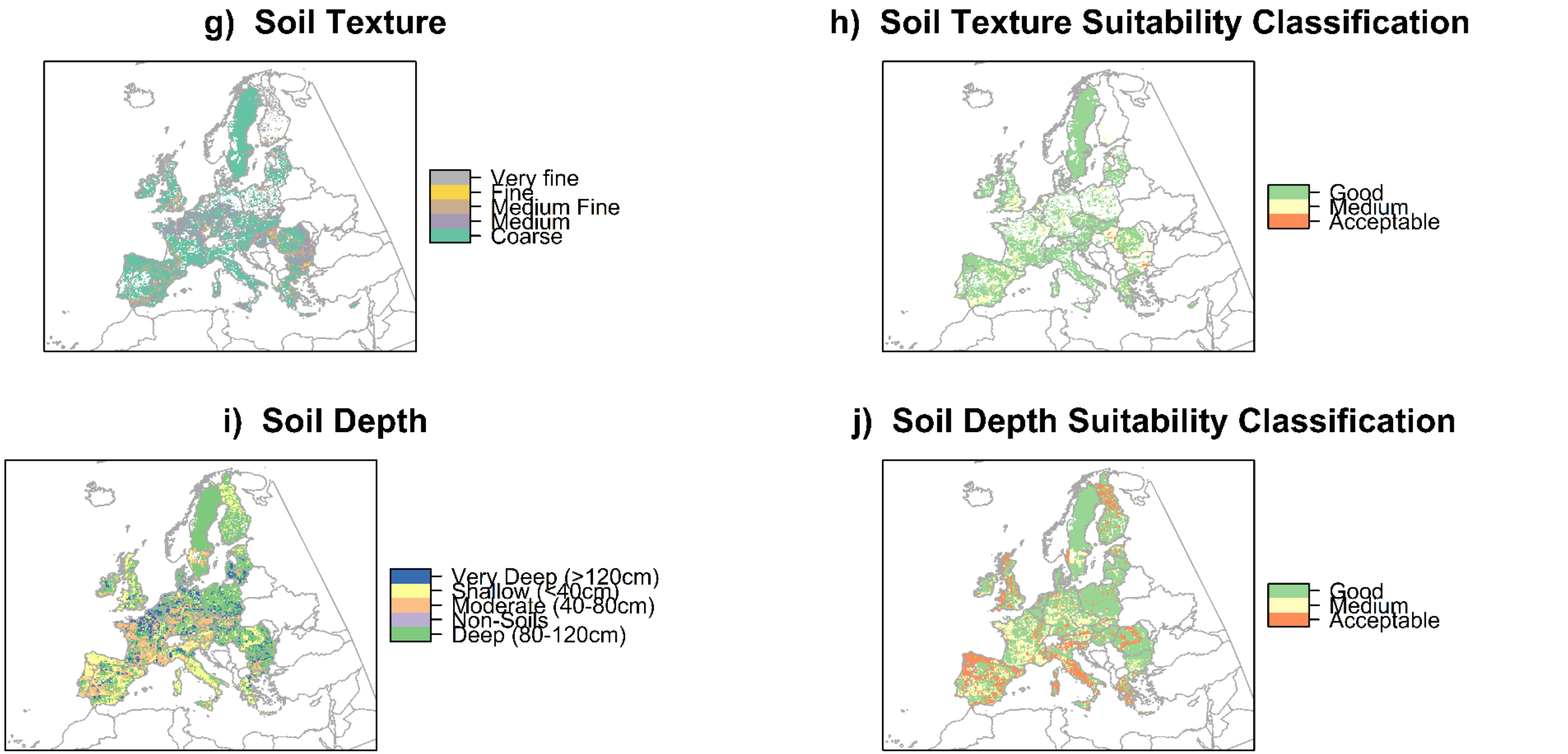


Figure 15. a-j Soil and hydrology variables and classified suitability.

3.2.3 Summary

In summary, the majority of Europe has soil and climate conditions that would allow camelina cultivation to be successful. This was expected as camelina is a relatively hardy oil crop, and is comparable to others currently farmed across the continent. Overall, southern Europe has a slightly more preferable climate for production, as camelina preferentially requires warm and dryer conditions to wet and mild. Ideal soil conditions are more spatially variable. Large areas of Spain, Germany and France have high composite scores for soil suitability. With only Finland and Scotland showing poor soil potential, due to the presence of dense peaty soils.

The cultivation of camelina is therefore limited by the availability of low-iLUC land, not by climate or environmental factors. Whereas certain regions may be preferable for camelina production, a majority of the European continent could potentially support cultivation. The following sections will address the distribution and extent of low-iLUC land.

4 Fallow land in the EU

4.1 Definition of fallow land

The EEA defines fallow land as "Arable land not under rotation that is set at rest for a period of time ranging from one to five years before it is cultivated again, or land usually under permanent crops, meadows or pastures, which is not being used for that purpose for a period of at least one year. Arable land which is normally used for the cultivation of temporary crops but which is temporarily used for grazing is included" [10]. The EEA definition of fallow land is somewhat difficult to interpret, but Eurostat provide a clearer, more concise definition. Eurostat define fallow land as "all arable land included in the crop rotation system, whether worked or not, but with no intention to produce a harvest for the duration of the crop year. The essential characteristic of fallow land is that it is left to recover normally for the whole crop year"[11]. Eurostat goes on to give three possible land uses associated with fallow land. These are:

1) Bare land bearing no crops at all.
2) Land with spontaneous natural growth which may be used as feed or ploughed in.
3) Land sown exclusively for the production of green manure (green fallow).

Although the EEA and Eurostat definitions broadly agree, there are some differences that may affect interpretation of patterns in fallow land usage within the EU. The EEA definition covers a broad temporal range, with 'one to five years' stated as the time that land may be left fallow for. The Eurostat definition is not temporally explicit in the sense that no maximum time period is given for arable land to be considered fallow, however it is implied that at least one year must pass without harvest of a crop before arable land is considered fallow. As the primary source of fallow land data used in this project was sourced from Eurostat, the Eurostat definition is the most applicable and as such will be used for the purposes of this project.

Although some studies categorise fallow land as inherently unmanaged in contrast to managed land (e.g. Kuemmerle et al., 2016), others recognise that management may form part of the characteristic of a fallow regime. For example, Lasanta et al. (2000) incorporate three possible fallow scenarios into their study on the transition between active farmland and abandoned land in a semi-arid region of Spain; fallow land that is ploughed, fallow land that is ploughed and treated with chemical fertiliser and fallow land that is ploughed and treated with organic fertiliser. The Eurostat definition of fallow land acknowledges that management is not an inherent characteristic of fallow land, however 'whether worked or not', the land must be left to recover from arable crop growth for at least one whole crop year. The governmental body responsible for agricultural subsidies in England- the Rural Payments Agency (RPA) provides guidance on what qualifies as fallow land for the Basic Payment Scheme (BPS) (Rural Payments Agency, 2016b). Complications in the application of the term 'fallow land' become apparent even *within* a single EU28 member, with three separate options available for farmers who wish to claim subsidies for allowing land to lay fallow. If the rationale is to promote crop diversification, then the land qualifies if left fallow (i.e. no grazing or crop production) from May until June, but is maintained in a state suitable for grazing or cultivation. If the rationale is to promote ecological enhancement, then the land must be left fallow from January until June with the caveat that a mix of at least two unharvestable crops suitable for wild-bird seed, pollen sources and nectar sources can be sown during this period- however the land must be maintained in a state suitable for future grazing or cultivation. A third option exists

[10] http://glossary.eea.europa.eu/EEAGlossary/F/fallow_land (Accessed October 2016).

[11] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Fallow_land (Accessed October 2016).

known as the 'two year sown legume fallow' option, however this appears to be classified separately to the previous examples. This requires sowing a recommended seed mix and managing appropriately over a two year period with the aim of enhancing wildlife and reducing blackgrass populations. The rules are complex as highlighted by a 113 page rulebook for the BPS in England (Rural Payments Agency, 2016a). Declarations on land use by farmers may vary, depending on the timing of their activities and a multitude of other factors. For example, a farmer may choose to declare land as either fallow or cover crop if both criteria are met in the same year; however they cannot declare the same plot of land as both within the same year for the purpose of Ecological Focus Area (EFA) subsidy. This means that while some farmers may declare a plot of land as fallow for subsidy, others may choose to declare the same plot as cover crop within the same year. Other complications and nuances are likely to exist across the EU28, probably depending on variables such as climatic and cultural specifics. No investigation has been made into national nuances of fallow land outside of England, however it is likely that the general nature of the Eurostat definition of fallow land takes variation into account.

4.2 Data source: cover and limitations

The dataset used for the analysis of fallow land at Nomenclature of Territorial Units for Statistics NUTS-2 level within the EU-28 was "Land use: number of farms and areas of different crops by agricultural size of farm (utilized agricultural area UAA) and NUTS 2 regions" (Code name 'ef_oluaareg'), provided freely by Eurostat[12], and compiled by the Agriculture and fisheries unit of Eurostat. This dataset is based on data collected through the Farm Structure Surveys (FSS), which requires EU member states to undertaken a census of agricultural activity every ten years, with intermediate surveys undertaken two or three times between censuses. Although the FSS undertaken by member states are designed to be comparable, some member states may undertake a full scope agricultural census for the ten year surveys and a sub-sample for the intermediate surveys, whereas other may use a sub-sample for both census and intermediate surveys[13]. The last full agricultural census for which this dataset covers was in 2010, with data from intermediate surveys available for 2005, 2007 and 2013. The data for 2013 are listed as 'provisional' within the metadata[4], however no reference is made to what is meant by this. In addition, the metadata is blanket information for all datasets provided by Eurostat relating to agricultural holdings and is not specific to fallow land, or indeed any data within ef_oluaareg.

The spatial resolution of the FSS data is theoretically higher in the years of the full agricultural censuses, with country, region and district compiled by Eurostat. For other years, only country and region were compiled. There was no apparent difference in resolution between the 2010 data and other years, with all data presented at a maximum resolution of NUTS2. Germany was an exception to this, with data available at NUTS1. The 2010 data follow the classification scheme presented by NUTS 2010, which was updated from the previous NUTS 2003 and NUTS 2006 and has since been superseded by NUTS 2013. These changes in NUTS classification reflect changes in boundaries, nomenclature or addition of new member states over time. Although NUTS 2013 only came into force in 2015, it is unclear whether the 2013 fallow land data within ef_oluaareg follow the NUTS 2010 or the NUTS 2013 classification. In addition, some regions are only available for NUTS 2006 within the dataset. This presents significant problems when attempting to map these data geographically by year. In order to resolve this issue, NUTS regional codes from ef_oluaareg were cross referenced to the classifications for NUTS 2006, NUTS 2010 and NUTS 2013. Where there was more than one match, it was assumed that the regional code referred to the latest version of the NUTS code that was available for. For example, Corse in France (NUTS code FR83) exists in NUTS 2006 and NUTS 2010, but not NUTS 2013. As such, it was assumed

[12] http://ec.europa.eu/eurostat/web/products-datasets/-/ef_oluaareg (Accessed October 2016).

[13] http://ec.europa.eu/eurostat/cache/metadata/en/ef_esms.htm (Accessed October 2016).

that all fallow data for Corse corresponded with the NUTS 2010 classification. Some exceptions to this rule exist, for example Etelä-Suomi in Finland (NUTS code FI1C) is recognized by NUTS 2010 and NUTS 2013 but not NUT2006. In theory, all fallow data for Etelä-Suomi should then correspond to the regional boundary presented within NUTS 2013, however data is absent for this region for 2013. As it is stated that 2010 data correspond to NUTS 2010, then this should be the classification used. However, it was assumed for the purpose of this study that if the regional code existed in multiple NUTS classifications, then the region was identical between those years. As such, the NUTS 2013 regional boundary was used to represent the 2010 Etelä-Suomi fallow land boundary. Etelä-Suomi is further complicated by the fact that a second NUTS code (FI13) exists for NUTS 2006 with data for 2005 and 2007. Although this appears problematic, it actually reinforces the methodology employed above, as regional changes with the same nomenclature appear to be allocated separate NUTS codes. The years of corresponding NUTS classifications for each region associated with the fallow land data can be found in table 5.

In some regions, only one NUTS classification corresponded to the fallow land data, in which case, this version of NUTS was used. Examples of this include Ionia Nisia in Greece (NUTS code EL22) which was only available in NUTS 2010 and Cheshire in the UK (NUTS code UKD2) which was only available in NUTS 2006. In cases where NUTS codes for the fallow land data did not correspond to all three NUTS classifications, there were often data deficiencies within some years. Using the example of Cheshire again, 2010 and 2013 data were not available, however 2005 and 2007 were. Ionia Nisia presents an example contrary to this however, as all fours years are available despite only being recognized by NUTS 2010. This suggests that retrospective application of NUTS region to data occurs in some case, whereas in others it does not.

In addition to the lack of data for some years in some regions as outlined above, other data deficiencies occur throughout the dataset, most notably within the latest year available, 2013. The reason for this is unclear, however the metadata states that 2013 is ‘provisional’ data. This suggests that compilation of fallow land data for 2013 is not complete, and may explain the lack of data for many regions in this year.

4.3 EU28 Country level fallow land availability

A general crop statistics dataset sourced from Eurostat (originally coded ‘tag00011’, but now under the apro_acs code family) was used for country level fallow land availability assessment. This dataset had lower resolution than ef_oluaareg[14], however the temporal resolution was higher, with annual data available. Values for area of fallow land per EU member state from 2000 to 2013 in 1,000 ha are presented in *Table 4*. Spain consistently had the highest land cover of fallow land across all years between 2002 and 2013, with over three million hectares in each year. Poland achieved over two million hectares of fallow land in 2002, with a decrease to between one and two million hectares of fallow land between 2003 and 2006 and subsequently below one million hectares of fallow land between 2006 and 2013. Despite this gradual decrease in availability of fallow land, it maintained one of the highest areas of fallow land within the EU-28 across all years from 2002 to 2013. Only two other member nations achieved over one million hectares of fallow land in a year between 2002 and 2013, France in all years between 2002 and 2007, and Romania in 2006. Other EU-28 countries with moderate areas of fallow land between the years 2002 and 2013 were Bulgaria, Finland, Germany, Greece, Hungary, Italy, Portugal, Sweden and the United Kingdom. The general trend in almost all countries was a gradual decrease in areas of fallow land between 2002 and 2013.

[14] For ef oluaareg see http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_oluaareg&lang=en

Table 4. Recorded area of fallow land in the EU-28 (in 1,000 ha) for years 2002 to 2013. Source: Eurostat

Country	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Belgium	27.5	29.9	23.6	27.8	27.6	24.6	12.3	10.1	9.59	7.31	8.48	8.46
Bulgaria	315.7	577.7	489.2	489.8	555.1	570.4	274.7	234.3	173.31	174.11	128.097	121.289
Czech Republic	83.2	177	54.5	45.3	43.7	30.3	23.4	28.5	45.047	28.283	32.847	23.78
Denmark	204.7	204.7	197	168.4	167.5	153.7	70.7	5.7	5.7	4.367	6.322	:
Germany	834.6	938.7	784.4	793.8	741.1	648.2	309.5	245.6	252.386	228.7	214.6	198.9
Estonia	25.2	27.5	22.4	29.9	19.1	18.8	19.5	28.9	42.2	46.2	50.8	41
Ireland	18.3	14.9	15	16.4	18.4	17.6	9.5	9.2	4.606	1.318	0.978	1.664
Greece	485.8	449.1	460.6	469.2	101.5	130.5	210	210	158.69	157.03	155.35	151.38
Spain	3195.1	3353.1	3273.4	3319.2	3799.9	3894.9	3179	3733.4	3733.4	3456.525	3423.01	3155.576
France	1280.2	1319.3	1153.2	1310	1268.3	1231.8	739.8	691.6	649.36	549.641	504.669	488.472
Croatia	19	25.2	32.3	15.3	16.6	16.9	12.7	13.1	11.633	11.2	11.152	4.889
Italy	678.8	630.7	672	620	474.7	474.7	494.2	494.2	:	:	:	:
Cyprus	6.9	5.4	10.5	20.5	16	20.5	20.7	13.8	9.5	12.301	11.421	11.584
Latvia	94	104.7	107.3	90.7	86.6	62.4	56.3	53.3	69.9	70.4	55.6	61.7
Lithuania	193.1	153.8	185.6	155.9	125	108	112.9	107.8	119.5	106.2	85.9	91.3
Luxembourg	1.8	1.8	1.2	1.9	1.4	1.3	0.1	0.1	0.139	0.163	0.291	0.157
Hungary	295.2	259.6	136.9	243.1	358.9	394	278.2	331.2	240.368	236.446	136.004	145.152
Malta	0.2	0.7	1.1	0.8	1.1	0.7	0.7	0.7	1.006	1.007	1.007	5.29
Netherlands	30	27.8	23.6	33.3	18.7	17.1	7.6	7.4	7.317	7.243	7.8	8.2
Austria	101	103.1	91.7	95.3	93.2	75.6	47.8	45.1	41.765	40.836	38.655	38.575
Poland	2321.3	1785.3	1442.7	1062	1025.4	440.9	491.5	528.2	449.8	468.4	439.9	446.5
Portugal	539.3	527.5	527.5	373.7	373.7	325.1	325.2	341.5	324.169	305.803	301.107	333.072
Romania	375.4	497.9	387.2	517.4	1055.5	898.1	922.6	904.8	1339.078	913.153	739.316	579.556
Slovenia	0.5	0.3	1.3	2.1	0.9	1.9	0.6	0.7	0.349	0.479	0.487	0.448
Slovakia	3.6	5	10.8	10.3	14.5	11	20.9	13.1	33.96	27.6	22.61	24.5038
Finland	210	220.4	195.9	241.3	253.3	231.6	188.5	229.8	306.9	277	267.3	254
Sweden	268.9	275.9	264	319.8	305.7	279.3	150.5	157.2	180.6	154.8	151.3	157.5
United Kingdom	34	32.9	:	140	150	165	175	244	174	156	156	156
Total	11643.3	11749.9	10564.9	10613.2	11113.4	10244.9	8154.4	8683.3	8384.273	7442.515	6951.003	6508.948

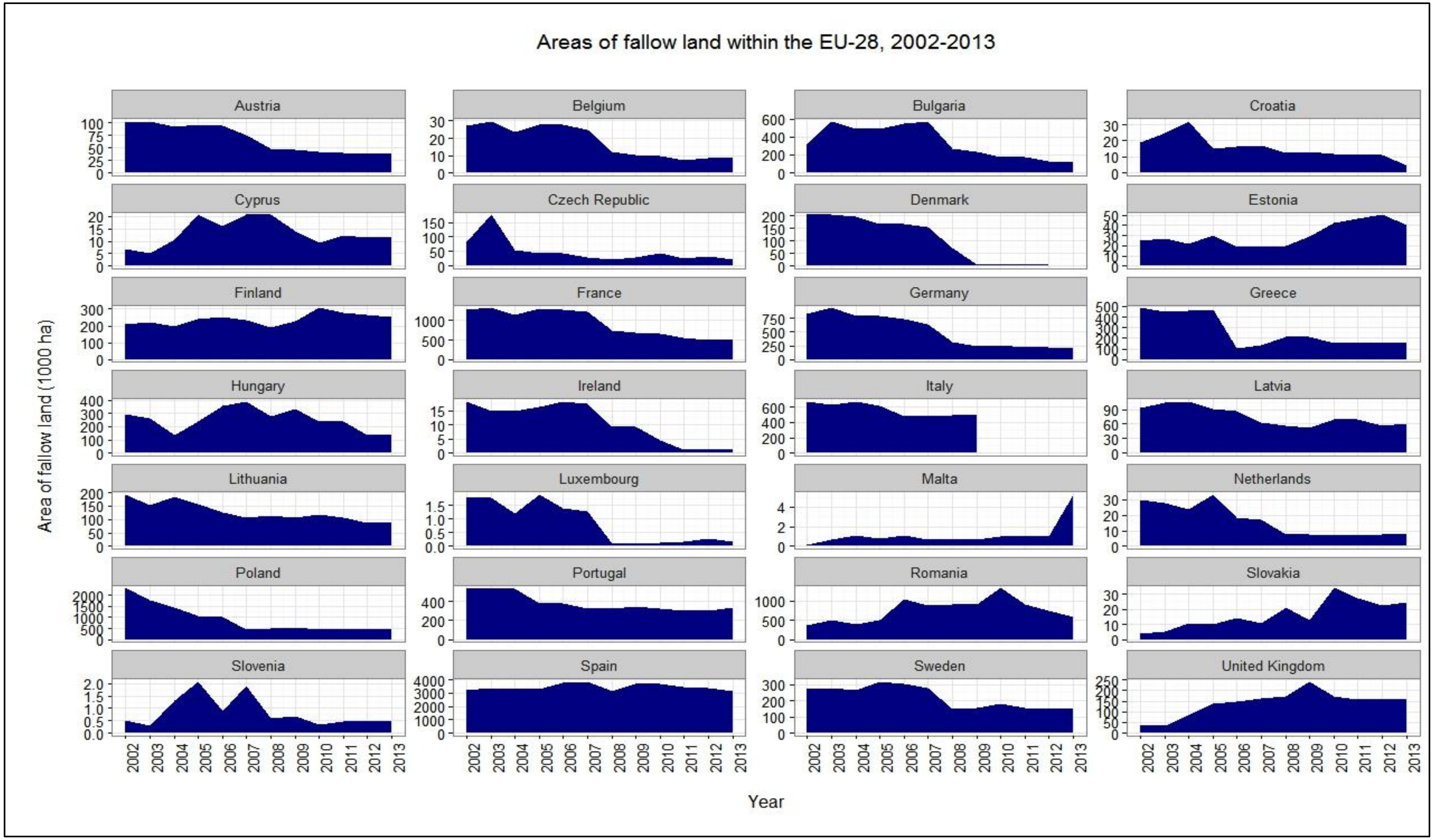


Figure 16. Recorded areas of fallow land by EU-28 member state covering the period 2002-2013. Y-axes are scaled mean graphical areas are not directly comparable between countries. Source: Eurostat.

4.4 EU28 NUTS-2 level fallow land availability

Using the 'Land use: number of farms and areas of different crops by agricultural size of farm (UAA) and NUTS 2 regions' dataset sourced from Eurostat, fallow land areas were extracted for NUTS-2 regions across the EU28 (where data was available) for the years 2005, 2007, 2010 and 2013 (Table 5). These data are represented as maps in Figures 17, 18, 19 and 20.

The NUTS-2 regions with the largest areas of fallow land were consistently in Spain across all four years, by quite a considerable margin (Figure 21). In all four years, Castilla-la Mancha, Castilla y León and Aragon were the three NUTS-2 regions with the largest area of fallow land across the EU-28 (Figure 22). In 2005, 2007 and 2013, Andalucía had the fourth largest area of fallow land, however in 2010 the region of Vest in Romania had the fourth largest area. Other countries that had large areas of fallow land within individual NUTS-2 regions across the four years include Portugal, France, Poland and Lithuania (Figure 22).

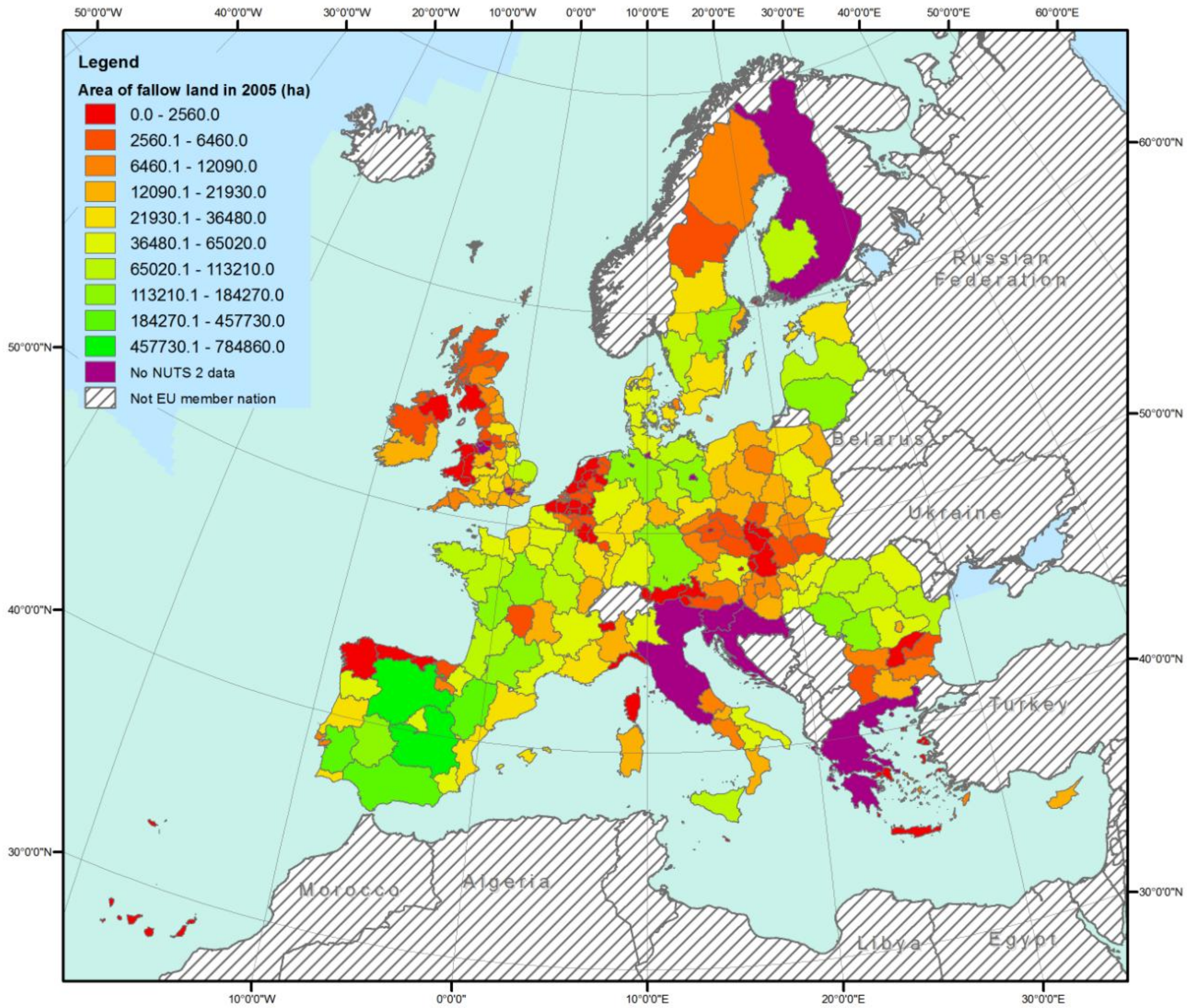


Figure 17. Fallow land area by NUTS-2 region within the EU for 2005. Germany is represented at NUTS-1 level due to data limitations. Data source: Eurostat.

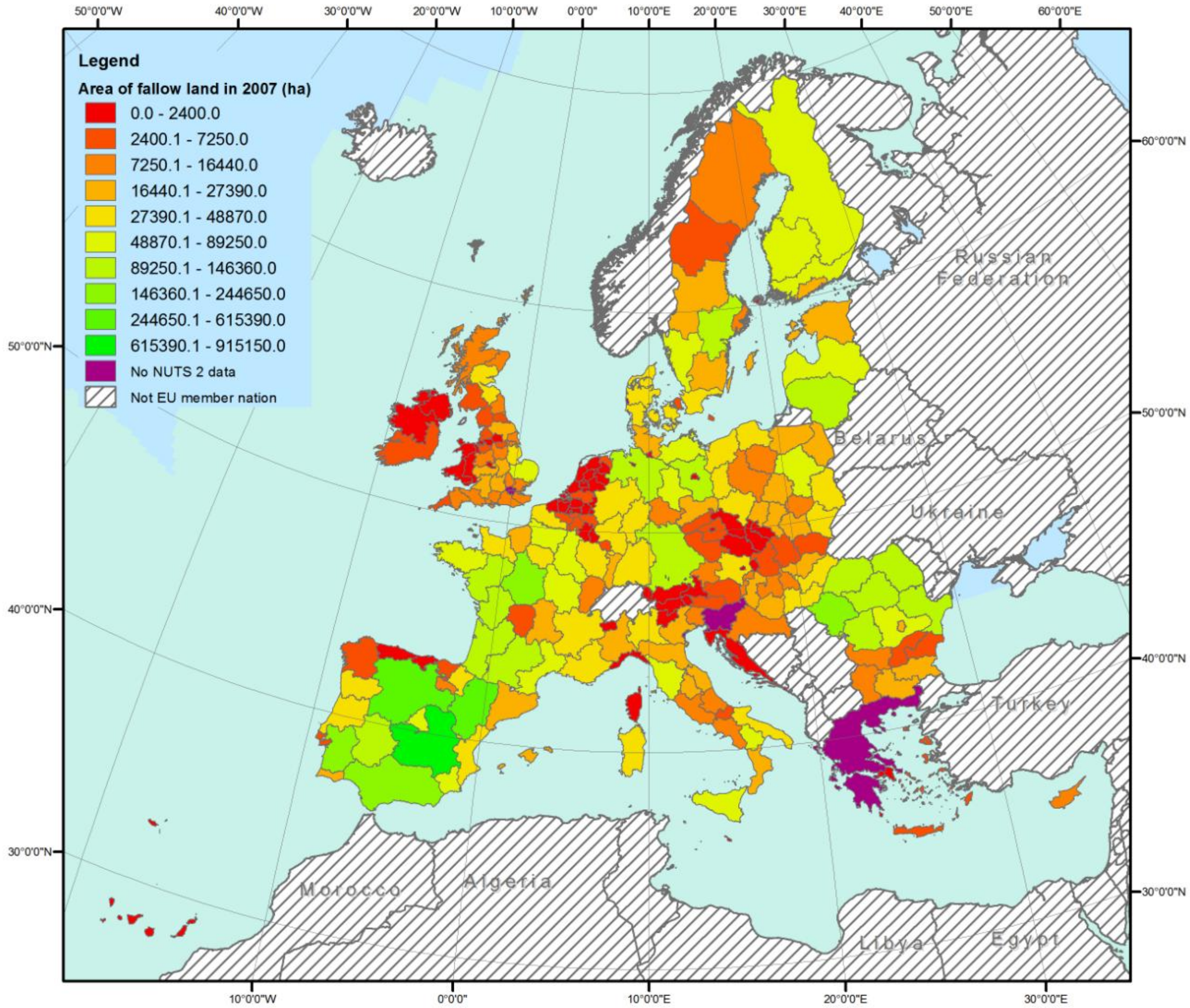


Figure 18. Fallow land area by NUTS-2 region within the EU for 2007. Germany is represented at NUTS-1 level due to data limitations. Data source: Eurostat.

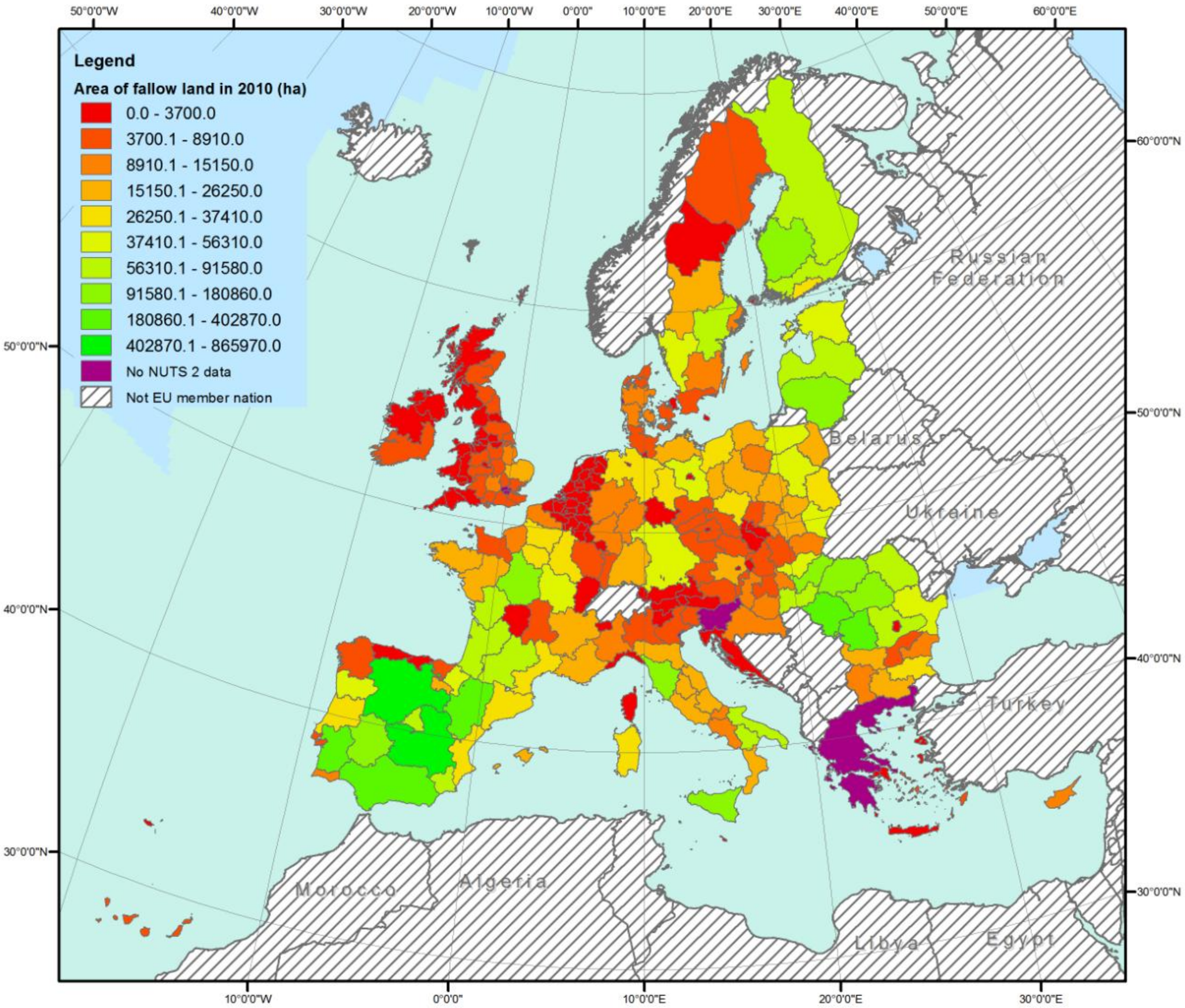


Figure 19. Fallow land area by NUTS-2 region within the EU for 2010. Germany is represented at NUTS-1 level due to data limitations. Data source: Eurostat.

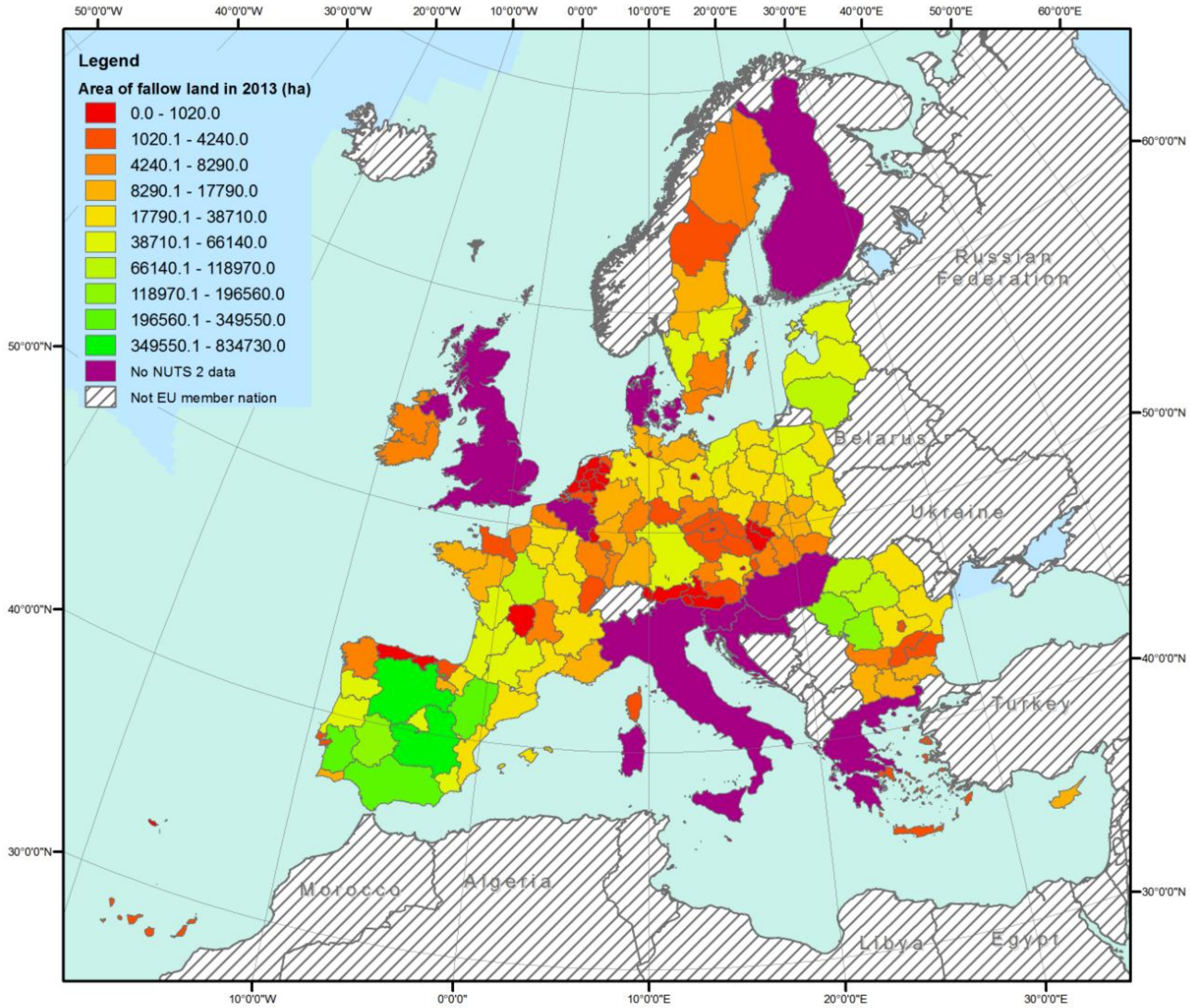


Figure 20. Fallow land area by NUTS-2 region within the EU for 2013. Germany is represented at NUTS-1 level due to data limitations. Data source: Eurostat.

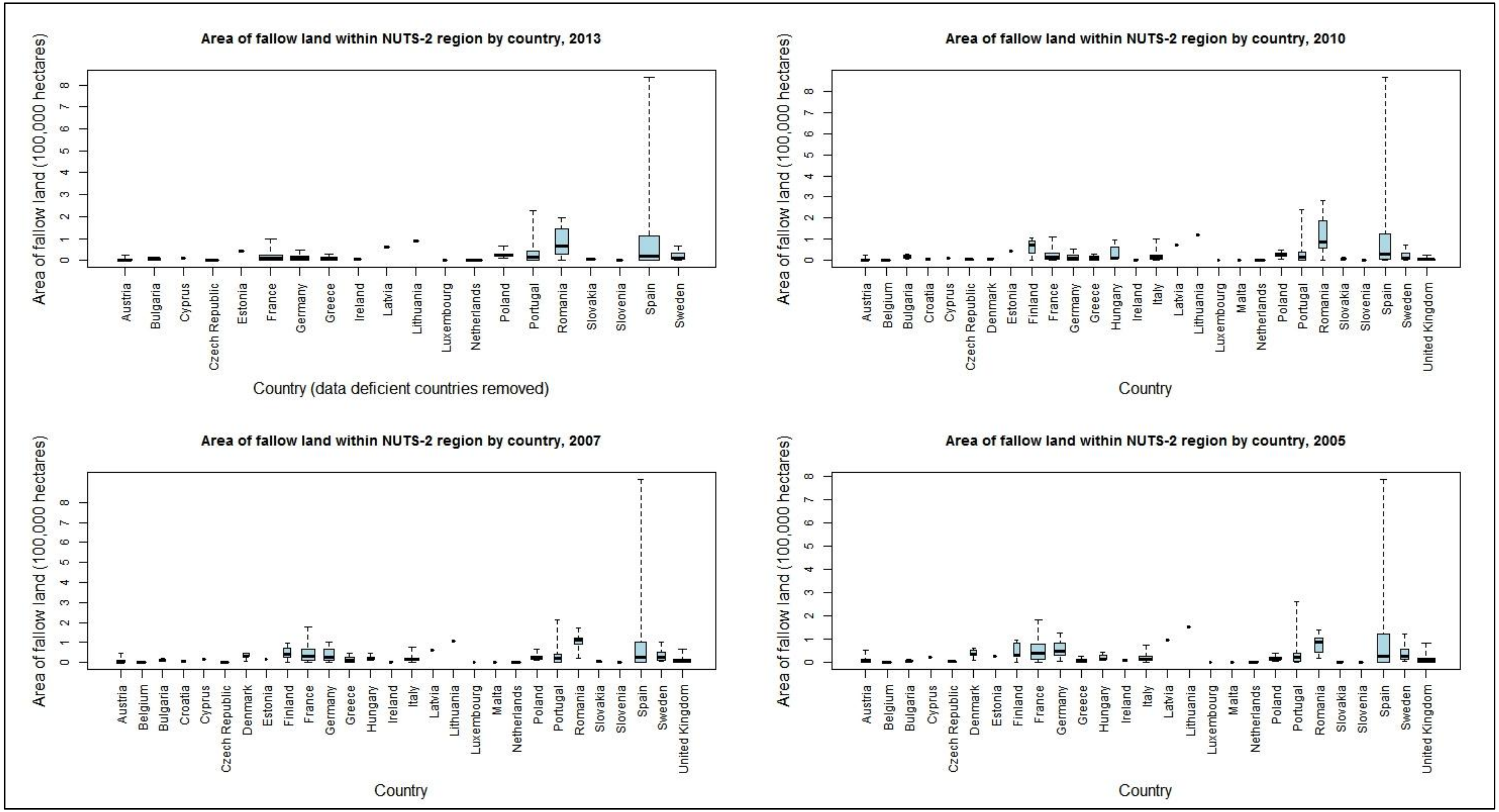


Figure 21. Area of fallow land within NUTS-2 regions by country for the years 2005, 2007, 2009 and 2013. Whiskers represent largest and smallest areas of fallow land within a country and boxes represent interquartile range. Width is proportional to the number of NUTS-2 regions represented. Where data was not available for an EU member nation within a particular year, these nations are not displayed. Data source: Eurostat.

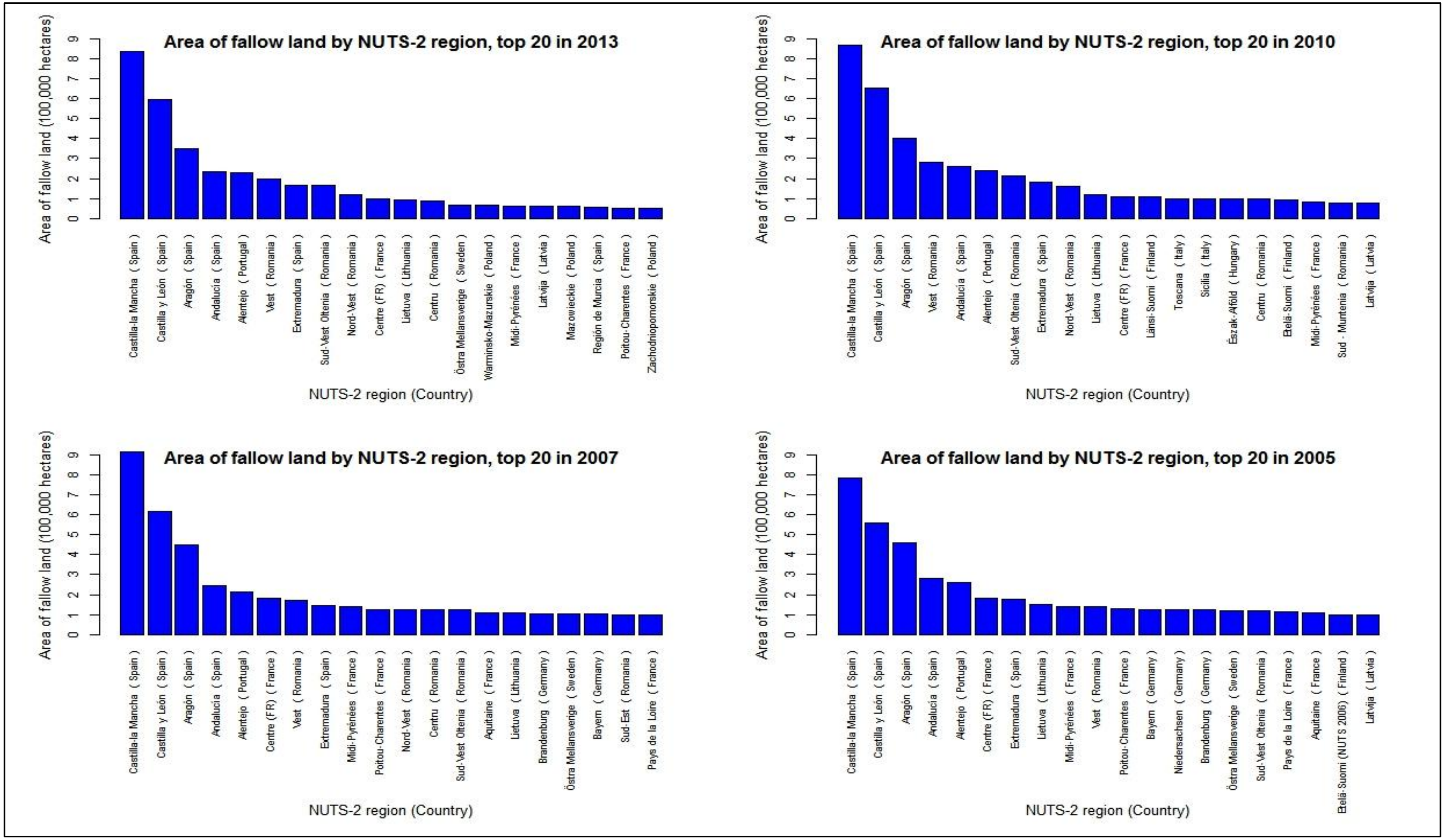


Figure 22. Top twenty NUTS-2 regions in terms of fallow land area for the years 2005, 2007, 2010 and 2013. Data source: Eurostat.

Table 5. The distribution of fallow land (ha) across the EU-28 at NUTS-2 resolution for the years 2013, 2010, 2007 and 2005. Data are sourced from Eurostat and deficiencies are as indicated. [Note table runs to several pages]

Country	Geopolitical entity	NUTS code	NUTS Level	Year of NUTS classification	Area in hectares, 2013	Area in hectares, 2010	Area in hectares, 2007	Area in hectares, 2005
Austria	Burgenland (AT)	AT11	NUTS 2	2006, 2010, 2013	6,120	7,280	14,790	18,800
Austria	Niederösterreich	AT12	NUTS 2	2006, 2010, 2013	22,150	23,880	44,200	54,610
Austria	Wien	AT13	NUTS 2	2006, 2010, 2013	240	270	410	560
Austria	Kärnten	AT21	NUTS 2	2006, 2010, 2013	1,020	1,060	2,750	3,530
Austria	Steiermark	AT22	NUTS 2	2006, 2010, 2013	3,130	4,050	5,870	7,230
Austria	Oberösterreich	AT31	NUTS 2	2006, 2010, 2013	5,450	6,230	10,490	14,380
Austria	Salzburg	AT32	NUTS 2	2006, 2010, 2013	160	90	50	30
Austria	Tirol	AT33	NUTS 2	2006, 2010, 2013	170	190	0	10
Austria	Vorarlberg	AT34	NUTS 2	2006, 2010, 2013	40	50	10	10
Belgium	Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	BE10	NUTS 2	2006, 2010, 2013	Data deficient	0	0	0
Belgium	Prov. Antwerpen	BE21	NUTS 2	2006, 2010, 2013	Data deficient	390	780	900
Belgium	Prov. Limburg (BE)	BE22	NUTS 2	2006, 2010, 2013	Data deficient	510	1,090	1,310
Belgium	Prov. Oost-Vlaanderen	BE23	NUTS 2	2006, 2010, 2013	Data deficient	520	1,020	1,210
Belgium	Prov. Vlaams-Brabant	BE24	NUTS 2	2006, 2010, 2013	Data deficient	780	2,100	2,540
Belgium	Prov. West-Vlaanderen	BE25	NUTS 2	2006, 2010, 2013	Data deficient	930	1,610	2,020
Belgium	Prov. Brabant Wallon	BE31	NUTS 2	2006, 2010, 2013	Data deficient	870	2,780	2,870
Belgium	Prov. Hainaut	BE32	NUTS 2	2006, 2010, 2013	Data deficient	2,200	6,320	7,190
Belgium	Prov. Liège	BE33	NUTS 2	2006, 2010, 2013	Data deficient	990	2,680	3,070
Belgium	Prov. Luxembourg (BE)	BE34	NUTS 2	2006, 2010, 2013	Data deficient	230	560	560
Belgium	Prov. Namur	BE35	NUTS 2	2006, 2010, 2013	Data deficient	2,180	5,660	6,120
Bulgaria	Severozapaden	BG31	NUTS 2	2006, 2010, 2013	4,680	19,360	10,310	9,590
Bulgaria	Severen tsentralen	BG32	NUTS 2	2006, 2010, 2013	1,750	6,680	5,160	1,520
Bulgaria	Severoiztochen	BG33	NUTS 2	2006, 2010, 2013	2,810	11,440	3,800	6,070
Bulgaria	Yugoiztochen	BG34	NUTS 2	2006, 2010, 2013	11,970	29,980	18,040	7,670
Bulgaria	Yugozapaden	BG41	NUTS 2	2006, 2010, 2013	11,310	15,150	9,220	6,460
Bulgaria	Yuzhen tsentralen	BG42	NUTS 2	2006, 2010, 2013	13,090	23,870	19,110	13,750
Croatia	Jadranska Hrvatska	HR03	NUTS 2	2006, 2010, 2013	Data deficient	1,290	1,760	Data deficient
Croatia	Kontinentalna Hrvatska	HR04	NUTS 2	2010, 2013	Data deficient	10,040	11,260	Data deficient
Cyprus	Kypros	CY00	NUTS 2	2006, 2010, 2013	10,250	9,460	16,400	20,450
Czech Republic	Praha	CZ01	NUTS 2	2006, 2010, 2013	0	70	660	1,390
Czech Republic	Strední Cechy	CZ02	NUTS 2	2006, 2010, 2013	2,090	5,460	2,680	4,320
Czech Republic	Jihozápad	CZ03	NUTS 2	2006, 2010, 2013	1,640	7,440	2,910	8,380
Czech Republic	Severozápad	CZ04	NUTS 2	2006, 2010, 2013	2,240	5,770	4,290	8,320
Czech Republic	Severovýchod	CZ05	NUTS 2	2006, 2010, 2013	2,230	6,560	2,280	4,080
Czech Republic	Jihovýchod	CZ06	NUTS 2	2006, 2010, 2013	2,090	7,850	1,750	3,160
Czech Republic	Strední Morava	CZ07	NUTS 2	2006, 2010, 2013	890	2,590	670	1,190

Country	Geopolitical entity	NUTS code	NUTS Level	Year of NUTS classification	Area in hectares, 2013	Area in hectares, 2010	Area in hectares, 2007	Area in hectares, 2005
Czech Republic	Moravskoslezsko	CZ08	NUTS 2	2006, 2010, 2013	410	1,730	480	820
Denmark	Hovedstaden	DK01	NUTS 2	2006, 2010, 2013	Data deficient	1,890	6,210	7,410
Denmark	Sjælland	DK02	NUTS 2	2006, 2010, 2013	Data deficient	7,250	30,470	35,440
Denmark	Syddanmark	DK03	NUTS 2	2006, 2010, 2013	Data deficient	9,650	44,550	52,170
Denmark	Midtjylland	DK04	NUTS 2	2006, 2010, 2013	Data deficient	10,020	48,870	59,570
Denmark	Nordjylland	DK05	NUTS 2	2006, 2010, 2013	Data deficient	5,940	29,360	33,300
Estonia	Eesti	EE00	NUTS 2	2006, 2010, 2013	40,960	42,160	17,580	27,740
Finland	Itä-Suomi (NUTS 2006)	FI13	NUTS 2	2006	Data deficient	Data deficient	31,320	32,340
Finland	Etelä-Suomi (NUTS 2006)	FI18	NUTS 2	2006	Data deficient	Data deficient	95,200	96,460
Finland	Länsi-Suomi	FI19	NUTS 2	2006, 2010, 2013	Data deficient	106,180	76,580	84,870
Finland	Pohjois-Suomi (NUTS 2006)	FI1A	NUTS 2	2006	Data deficient	Data deficient	23,090	26,320
Finland	Helsinki-Uusimaa	FI1B	NUTS 2	2010, 2013	Data deficient	36,070	25,800	Data deficient
Finland	Etelä-Suomi	FI1C	NUTS 2	2010, 2013	Data deficient	91,580	69,400	Data deficient
Finland	Pohjois- ja Itä-Suomi	FI1D	NUTS 2	2010, 2013	Data deficient	72,040	54,410	Data deficient
Finland	Åland	FI20	NUTS 2	2006, 2010, 2013	Data deficient	1,080	1,240	1,100
France	Île de France	FR10	NUTS 2	2006, 2010, 2013	24,000	27,200	42,140	44,700
France	Champagne-Ardenne	FR21	NUTS 2	2006, 2010, 2013	25,020	32,130	62,720	74,090
France	Picardie	FR22	NUTS 2	2006, 2010, 2013	21,120	29,710	58,020	64,600
France	Haute-Normandie	FR23	NUTS 2	2006, 2010, 2013	5,770	10,600	27,390	29,020
France	Centre (FR)	FR24	NUTS 2	2006, 2010, 2013	97,000	110,050	180,040	184,270
France	Basse-Normandie	FR25	NUTS 2	2006, 2010, 2013	4,070	6,630	30,950	41,340
France	Bourgogne	FR26	NUTS 2	2006, 2010, 2013	30,850	41,460	72,990	77,080
France	Nord - Pas-de-Calais	FR30	NUTS 2	2006, 2010, 2013	7,820	11,010	30,910	40,970
France	Lorraine	FR41	NUTS 2	2006, 2010, 2013	5,010	7,490	31,140	36,480
France	Alsace	FR42	NUTS 2	2006, 2010, 2013	6,640	8,040	21,040	22,440
France	Franche-Comté	FR43	NUTS 2	2006, 2010, 2013	1,980	3,640	12,810	13,030
France	Pays de la Loire	FR51	NUTS 2	2006, 2010, 2013	9,580	22,040	95,940	113,210
France	Bretagne	FR52	NUTS 2	2006, 2010, 2013	10,570	16,900	67,370	85,530
France	Poitou-Charentes	FR53	NUTS 2	2006, 2010, 2013	52,890	66,200	126,000	131,340
France	Aquitaine	FR61	NUTS 2	2006, 2010, 2013	50,650	62,300	108,650	110,360
France	Midi-Pyrénées	FR62	NUTS 2	2006, 2010, 2013	63,680	84,290	138,340	139,610
France	Limousin	FR63	NUTS 2	2006, 2010, 2013	1,000	1,420	4,020	5,580
France	Rhône-Alpes	FR71	NUTS 2	2006, 2010, 2013	19,680	22,060	48,080	48,080
France	Auvergne	FR72	NUTS 2	2006, 2010, 2013	5,430	7,990	18,700	21,100
France	Languedoc-Roussillon	FR81	NUTS 2	2006, 2010, 2013	29,130	33,770	55,770	45,530
France	Provence-Alpes-Côte d'Azur	FR82	NUTS 2	2006, 2010, 2013	14,670	18,300	28,930	32,440
France	Corse	FR83	NUTS 2	2006, 2010, 2013	2,020	1,250	1,050	880
France	Guadeloupe (NUTS 2010)	FR91	NUTS 2	2006, 2010	2,260	1,230	1,540	2,300
France	Martinique (NUTS 2010)	FR92	NUTS 2	2006, 2010	1,950	2,060	2,560	1,810
France	Guyane (NUTS 2010)	FR93	NUTS 2	2006, 2010	530	410	1,940	1,440

Country	Geopolitical entity	NUTS code	NUTS Level	Year of NUTS classification	Area in hectares, 2013	Area in hectares, 2010	Area in hectares, 2007	Area in hectares, 2005
France	Réunion (NUTS 2010)	FR94	NUTS 2	2006, 2010	910	720	730	830
Germany	Baden-Württemberg	DE1	NUTS 1	2006, 2010, 2013	12,200	16,650	41,280	47,550
Germany	Bayern	DE2	NUTS 1	2006, 2010, 2013	47,020	55,550	102,220	125,470
Germany	Berlin	DE3	NUTS 1	2006, 2010, 2013	30	160	270	Data deficient
Germany	Brandenburg	DE4	NUTS 1	2006, 2010, 2013	33,490	44,990	103,550	121,990
Germany	Bremen	DE5	NUTS 1	2006, 2010, 2013	30	0	80	Data deficient
Germany	Hamburg	DE6	NUTS 1	2006, 2010, 2013	320	400	410	Data deficient
Germany	Hessen	DE7	NUTS 1	2006, 2010, 2013	8,050	9,370	28,370	32,010
Germany	Mecklenburg-Vorpommern	DE8	NUTS 1	2006, 2010, 2013	17,030	25,130	70,080	82,520
Germany	Niedersachsen	DE9	NUTS 1	2006, 2010, 2013	27,060	31,070	94,190	124,900
Germany	Nordrhein-Westfalen	DEA	NUTS 1	2006, 2010, 2013	9,700	11,410	42,540	56,650
Germany	Rheinland-Pfalz	DEB	NUTS 1	2006, 2010, 2013	8,760	11,780	28,400	30,850
Germany	Saarland	DEC	NUTS 1	2006, 2010, 2013	1,450	2,340	4,290	4,340
Germany	Sachsen	DED	NUTS 1	2006, 2010, 2013	4,900	5,760	24,490	29,450
Germany	Sachsen-Anhalt	DEE	NUTS 1	2006, 2010, 2013	18,650	27,840	65,460	78,870
Germany	Schleswig-Holstein	DEF	NUTS 1	2006, 2010, 2013	8,390	6,950	26,520	37,920
Germany	Thüringen	DEG	NUTS 1	2006, 2010, 2013	1,780	2,960	16,340	20,340
Greece	Anatoliki Makedonia, Thraki (NUTS 2010)	EL11	NUTS 2	2010	26,080	29,230	43,140	26,850
Greece	Kentriki Makedonia (NUTS 2010)	EL12	NUTS 2	2010	28,480	23,540	44,080	12,290
Greece	Dytiki Makedonia (NUTS 2010)	EL13	NUTS 2	2010	21,010	21,880	31,810	24,980
Greece	Thessalia (NUTS 2010)	EL14	NUTS 2	2010	13,170	12,870	21,170	10,010
Greece	Ipeiros (NUTS 2010)	EL21	NUTS 2	2010	1,520	1,450	2,270	2,280
Greece	Ionia Nisia (NUTS 2010)	EL22	NUTS 2	2010	1,880	1,480	2,740	1,530
Greece	Dytiki Ellada (NUTS 2010)	EL23	NUTS 2	2010	11,240	12,800	12,130	10,620
Greece	Sterea Ellada (NUTS 2010)	EL24	NUTS 2	2010	16,590	23,730	25,140	8,400
Greece	Peloponnisos (NUTS 2010)	EL25	NUTS 2	2010	10,110	10,660	12,160	11,790
Greece	Attiki	EL30	NUTS 2	2010, 2013	2,070	2,550	2,400	1,100
Greece	Voreio Aigaio	EL41	NUTS 2	2010, 2013	2,060	2,470	3,750	2,370
Greece	Notio Aigaio	EL42	NUTS 2	2010, 2013	4,240	6,800	6,690	7,580
Greece	Kriti	EL43	NUTS 2	2010, 2013	1,950	1,570	2,730	2,250
Hungary	Közép-Magyarország	HU10	NUTS 2	2006, 2010, 2013	Data deficient	11,230	14,030	13,890
Hungary	Közép-Dunántúl	HU21	NUTS 2	2006, 2010, 2013	Data deficient	8,910	10,910	10,220
Hungary	Nyugat-Dunántúl	HU22	NUTS 2	2006, 2010, 2013	Data deficient	10,730	17,420	10,640
Hungary	Dél-Dunántúl	HU23	NUTS 2	2006, 2010, 2013	Data deficient	9,970	17,050	14,810
Hungary	Észak-Magyarország	HU31	NUTS 2	2006, 2010, 2013	Data deficient	56,310	24,580	23,920
Hungary	Észak-Alföld	HU32	NUTS 2	2006, 2010, 2013	Data deficient	97,500	31,130	41,300
Hungary	Dél-Alföld	HU33	NUTS 2	2006, 2010, 2013	Data deficient	65,380	44,690	45,810
Ireland	Border, Midland and Western	IE01	NUTS 2	2006, 2010, 2013	6,720	540	1,020	3,260
Ireland	Southern and Eastern	IE02	NUTS 2	2006, 2010, 2013	7,570	4,060	5,230	12,900
Italy	Piemonte	ITC1	NUTS 2	2006, 2010, 2013	Data deficient	15,100	17,890	21,930

Country	Geopolitical entity	NUTS code	NUTS Level	Year of NUTS classification	Area in hectares, 2013	Area in hectares, 2010	Area in hectares, 2007	Area in hectares, 2005
Italy	Valle d'Aosta/Vallée d'Aoste	ITC2	NUTS 2	2006, 2010, 2013	Data deficient	110	40	10
Italy	Liguria	ITC3	NUTS 2	2006, 2010, 2013	Data deficient	640	60	30
Italy	Lombardia	ITC4	NUTS 2	2006, 2010, 2013	Data deficient	6,780	32,740	39,730
Italy	Provincia Autonoma Bolzano/Bozen (NUTS 2006)	ITD1	NUTS 2	2006	Data deficient	Data deficient	0	10
Italy	Provincia Autonoma Trento (NUTS 2006)	ITD2	NUTS 2	2006	Data deficient	Data deficient	90	20
Italy	Veneto (NUTS 2006)	ITD3	NUTS 2	2006	Data deficient	Data deficient	17,770	18,580
Italy	Friuli-Venezia Giulia (NUTS 2006)	ITD4	NUTS 2	2006	Data deficient	Data deficient	10,650	9,370
Italy	Emilia-Romagna (NUTS 2006)	ITD5	NUTS 2	2006	Data deficient	Data deficient	20,410	26,880
Italy	Toscana (NUTS 2006)	ITE1	NUTS 2	2006	Data deficient	Data deficient	62,990	68,340
Italy	Umbria (NUTS 2006)	ITE2	NUTS 2	2006	Data deficient	Data deficient	18,430	12,980
Italy	Marche (NUTS 2006)	ITE3	NUTS 2	2006	Data deficient	Data deficient	17,770	19,160
Italy	Lazio (NUTS 2006)	ITE4	NUTS 2	2006	Data deficient	Data deficient	13,620	11,760
Italy	Abruzzo	ITF1	NUTS 2	2006, 2010, 2013	Data deficient	19,520	9,900	8,280
Italy	Molise	ITF2	NUTS 2	2006, 2010, 2013	Data deficient	14,430	7,250	13,550
Italy	Campania	ITF3	NUTS 2	2006, 2010, 2013	Data deficient	14,790	16,440	12,090
Italy	Puglia	ITF4	NUTS 2	2006, 2010, 2013	Data deficient	71,930	48,040	46,710
Italy	Basilicata	ITF5	NUTS 2	2006, 2010, 2013	Data deficient	61,910	73,120	52,300
Italy	Calabria	ITF6	NUTS 2	2006, 2010, 2013	Data deficient	16,680	20,520	15,510
Italy	Sicilia	ITG1	NUTS 2	2006, 2010, 2013	Data deficient	98,620	76,920	76,520
Italy	Sardegna	ITG2	NUTS 2	2006, 2010, 2013	Data deficient	35,900	29,540	19,690
Italy	Provincia Autonoma di Bolzano/Bozen	ITH1	NUTS 2	2010, 2013	Data deficient	50	0	Data deficient
Italy	Provincia Autonoma di Trento	ITH2	NUTS 2	2010, 2013	Data deficient	90	90	Data deficient
Italy	Veneto	ITH3	NUTS 2	2010, 2013	Data deficient	8,670	17,770	Data deficient
Italy	Friuli-Venezia Giulia	ITH4	NUTS 2	2010, 2013	Data deficient	5,040	10,650	Data deficient
Italy	Emilia-Romagna	ITH5	NUTS 2	2010, 2013	Data deficient	17,640	20,430	Data deficient
Italy	Toscana	ITI1	NUTS 2	2010, 2013	Data deficient	99,000	62,990	Data deficient
Italy	Umbria	ITI2	NUTS 2	2010, 2013	Data deficient	18,550	18,430	Data deficient
Italy	Marche	ITI3	NUTS 2	2010, 2013	Data deficient	23,260	17,760	Data deficient
Italy	Lazio	ITI4	NUTS 2	2010, 2013	Data deficient	19,040	13,620	Data deficient
Latvia	Latvija	LV00	NUTS 2	2006, 2010, 2013	60,340	74,450	62,430	95,660
Lithuania	Lietuva	LT00	NUTS 2	2006, 2010, 2013	90,600	118,780	107,900	151,090
Luxembourg	Luxembourg	LU00	NUTS 2	2006, 2010, 2013	160	140	1,350	1,860
Malta	Malta	MT00	NUTS 2	2006, 2010, 2013	Data deficient	1,010	680	1,120
Netherlands	Groningen	NL11	NUTS 2	2006, 2010, 2013	1,700	1,220	3,430	5,820
Netherlands	Friesland (NL)	NL12	NUTS 2	2006, 2010, 2013	370	270	760	2,140
Netherlands	Drenthe	NL13	NUTS 2	2006, 2010, 2013	590	520	1,490	3,060
Netherlands	Overijssel	NL21	NUTS 2	2006, 2010, 2013	200	210	730	1,950
Netherlands	Gelderland	NL22	NUTS 2	2006, 2010, 2013	450	590	1,630	3,390
Netherlands	Flevoland	NL23	NUTS 2	2006, 2010, 2013	570	350	990	1,950
Netherlands	Utrecht	NL31	NUTS 2	2006, 2010, 2013	100	60	200	300

Country	Geopolitical entity	NUTS code	NUTS Level	Year of NUTS classification	Area in hectares, 2013	Area in hectares, 2010	Area in hectares, 2007	Area in hectares, 2005
Netherlands	Noord-Holland	NL32	NUTS 2	2006, 2010, 2013	670	700	1,180	2,270
Netherlands	Zuid-Holland	NL33	NUTS 2	2006, 2010, 2013	480	460	910	2,180
Netherlands	Zeeland	NL34	NUTS 2	2006, 2010, 2013	680	760	1,810	3,660
Netherlands	Noord-Brabant	NL41	NUTS 2	2006, 2010, 2013	1,460	1,280	2,680	5,000
Netherlands	Limburg (NL)	NL42	NUTS 2	2006, 2010, 2013	920	840	1,250	2,560
Poland	Lódzkie	PL11	NUTS 2	2006, 2010, 2013	22,340	21,170	26,190	16,610
Poland	Mazowieckie	PL12	NUTS 2	2006, 2010, 2013	59,740	49,930	67,220	40,510
Poland	Malopolskie	PL21	NUTS 2	2006, 2010, 2013	12,750	26,250	17,770	7,690
Poland	Slaskie	PL22	NUTS 2	2006, 2010, 2013	12,700	14,460	23,520	15,000
Poland	Lubelskie	PL31	NUTS 2	2006, 2010, 2013	26,490	32,310	31,690	23,430
Poland	Podkarpackie	PL32	NUTS 2	2006, 2010, 2013	27,340	47,940	43,840	26,220
Poland	Swietokrzyskie	PL33	NUTS 2	2006, 2010, 2013	14,260	25,290	11,560	12,570
Poland	Podlaskie	PL34	NUTS 2	2006, 2010, 2013	21,530	17,870	19,220	15,450
Poland	Wielkopolskie	PL41	NUTS 2	2006, 2010, 2013	31,330	24,930	14,740	14,230
Poland	Zachodniopomorskie	PL42	NUTS 2	2006, 2010, 2013	51,760	33,740	33,440	26,910
Poland	Lubuskie	PL43	NUTS 2	2006, 2010, 2013	24,060	22,610	28,990	12,490
Poland	Dolnoslaskie	PL51	NUTS 2	2006, 2010, 2013	26,650	29,960	34,960	15,850
Poland	Opolskie	PL52	NUTS 2	2006, 2010, 2013	8,210	7,910	24,810	3,180
Poland	Kujawsko-Pomorskie	PL61	NUTS 2	2006, 2010, 2013	20,960	12,080	9,430	7,000
Poland	Warminsko-Mazurskie	PL62	NUTS 2	2006, 2010, 2013	64,950	44,520	22,510	24,750
Poland	Pomorskie	PL63	NUTS 2	2006, 2010, 2013	21,450	20,600	31,060	16,490
Portugal	Norte	PT11	NUTS 2	2006, 2010, 2013	46,630	44,440	48,470	50,180
Portugal	Algarve	PT15	NUTS 2	2006, 2010, 2013	13,220	14,350	23,060	23,200
Portugal	Centro (PT)	PT16	NUTS 2	2006, 2010, 2013	40,480	35,960	36,550	32,220
Portugal	Área Metropolitana de Lisboa	PT17	NUTS 2	2006, 2010, 2013	4,060	6,280	5,220	8,470
Portugal	Alentejo	PT18	NUTS 2	2006, 2010, 2013	228,640	240,450	211,740	259,580
Portugal	Região Autónoma dos Açores (PT)	PT20	NUTS 2	2006, 2010, 2013	0	0	0	0
Portugal	Região Autónoma da Madeira (PT)	PT30	NUTS 2	2006, 2010, 2013	40	70	20	50
Romania	Nord-Vest	RO11	NUTS 2	2006, 2010, 2013	118,970	159,880	124,720	91,590
Romania	Centru	RO12	NUTS 2	2006, 2010, 2013	89,180	96,530	123,600	84,430
Romania	Nord-Est	RO21	NUTS 2	2006, 2010, 2013	31,600	68,070	92,520	41,870
Romania	Sud-Est	RO22	NUTS 2	2006, 2010, 2013	28,360	51,770	100,030	88,470
Romania	Sud - Muntenia	RO31	NUTS 2	2006, 2010, 2013	38,220	75,650	89,250	44,050
Romania	Bucuresti - Ilfov	RO32	NUTS 2	2006, 2010, 2013	1,770	2,790	23,610	16,620
Romania	Sud-Vest Oltenia	RO41	NUTS 2	2006, 2010, 2013	167,100	215,780	122,390	118,750
Romania	Vest	RO42	NUTS 2	2006, 2010, 2013	196,560	282,040	170,750	138,120
Slovakia	Bratislavský kraj	SK01	NUTS 2	2006, 2010, 2013	1,490	2,280	920	750
Slovakia	Západné Slovensko	SK02	NUTS 2	2006, 2010, 2013	5,090	7,610	2,980	1,830
Slovakia	Stredné Slovensko	SK03	NUTS 2	2006, 2010, 2013	8,120	8,000	5,830	2,830
Slovakia	Východné Slovensko	SK04	NUTS 2	2006, 2010, 2013	6,450	13,680	5,990	4,500

Country	Geopolitical entity	NUTS code	NUTS Level	Year of NUTS classification	Area in hectares, 2013	Area in hectares, 2010	Area in hectares, 2007	Area in hectares, 2005
Slovenia	Vzhodna Slovenija (NUTS 2010)	SI01	NUTS 2	2006, 2010	280	270	1,180	1,560
Slovenia	Zahodna Slovenija (NUTS 2010)	SI02	NUTS 2	2006, 2010	130	80	700	550
Spain	Galicia	ES11	NUTS 2	2006, 2010, 2013	8,290	7,650	4,530	2,480
Spain	Principado de Asturias	ES12	NUTS 2	2006, 2010, 2013	70	80	20	20
Spain	Cantabria	ES13	NUTS 2	2006, 2010, 2013	620	870	110	270
Spain	País Vasco	ES21	NUTS 2	2006, 2010, 2013	2,830	6,580	4,520	4,490
Spain	Comunidad Foral de Navarra	ES22	NUTS 2	2006, 2010, 2013	38,710	42,660	45,450	45,470
Spain	La Rioja	ES23	NUTS 2	2006, 2010, 2013	9,780	17,360	10,600	10,720
Spain	Aragón	ES24	NUTS 2	2006, 2010, 2013	349,550	402,870	446,690	457,730
Spain	Comunidad de Madrid	ES30	NUTS 2	2006, 2010, 2013	50,850	62,710	57,800	51,580
Spain	Castilla y León	ES41	NUTS 2	2006, 2010, 2013	595,460	654,810	615,390	559,580
Spain	Castilla-la Mancha	ES42	NUTS 2	2006, 2010, 2013	834,730	865,970	915,150	784,860
Spain	Extremadura	ES43	NUTS 2	2006, 2010, 2013	167,540	180,860	146,360	175,300
Spain	Cataluña	ES51	NUTS 2	2006, 2010, 2013	19,450	29,310	25,810	32,300
Spain	Comunidad Valenciana	ES52	NUTS 2	2006, 2010, 2013	31,620	37,410	30,940	27,020
Spain	Illes Balears	ES53	NUTS 2	2006, 2010, 2013	19,510	20,120	21,820	23,870
Spain	Andalucía	ES61	NUTS 2	2006, 2010, 2013	235,000	262,610	244,650	281,990
Spain	Región de Murcia	ES62	NUTS 2	2006, 2010, 2013	55,990	67,880	56,720	65,020
Spain	Ciudad Autónoma de Ceuta (ES)	ES63	NUTS 2	2006, 2010, 2013	0	0	0	0
Spain	Ciudad Autónoma de Melilla (ES)	ES64	NUTS 2	2006, 2010, 2013	0	0	0	0
Spain	Canarias (ES)	ES70	NUTS 2	2006, 2010, 2013	3,430	4,210	1,760	1,970
Sweden	Stockholm	SE11	NUTS 2	2006, 2010, 2013	12,120	12,250	14,730	15,910
Sweden	Östra Mellansverige	SE12	NUTS 2	2006, 2010, 2013	66,140	74,130	103,050	120,830
Sweden	Småland med öarna	SE21	NUTS 2	2006, 2010, 2013	7,780	9,890	21,440	26,510
Sweden	Sydsverige	SE22	NUTS 2	2006, 2010, 2013	5,400	7,680	29,250	34,330
Sweden	Västsverige	SE23	NUTS 2	2006, 2010, 2013	44,660	49,220	71,100	77,560
Sweden	Norra Mellansverige	SE31	NUTS 2	2006, 2010, 2013	17,790	19,780	26,260	30,920
Sweden	Mellersta Norrland	SE32	NUTS 2	2006, 2010, 2013	1,460	1,440	3,770	5,630
Sweden	Övre Norrland	SE33	NUTS 2	2006, 2010, 2013	6,290	6,250	9,550	11,140
United Kingdom	Tees Valley and Durham	UKC1	NUTS 2	2006, 2010, 2013	Data deficient	2,220	5,190	7,710
United Kingdom	Northumberland and Tyne and Wear	UKC2	NUTS 2	2006, 2010, 2013	Data deficient	4,210	11,040	12,710
United Kingdom	Cumbria	UKD1	NUTS 2	2006, 2010, 2013	Data deficient	900	2,820	4,560
United Kingdom	Cheshire (NUTS 2006)	UKD2	NUTS 2	2006	Data deficient	Data deficient	3,870	5,060
United Kingdom	Greater Manchester	UKD3	NUTS 2	2006, 2010, 2013	Data deficient	240	750	950
United Kingdom	Lancashire	UKD4	NUTS 2	2006, 2010, 2013	Data deficient	1,150	2,810	3,700
United Kingdom	Merseyside (NUTS 2006)	UKD5	NUTS 2	2006	Data deficient	Data deficient	1,290	1,550
United Kingdom	Cheshire	UKD6	NUTS 2	2010, 2013	Data deficient	990	3,780	Data deficient
United Kingdom	Merseyside	UKD7	NUTS 2	2010, 2013	Data deficient	660	1,380	Data deficient
United Kingdom	East Yorkshire and Northern Lincolnshire	UKE1	NUTS 2	2006, 2010, 2013	Data deficient	7,060	15,910	20,930
United Kingdom	North Yorkshire	UKE2	NUTS 2	2006, 2010, 2013	Data deficient	8,090	21,750	28,050

Country	Geopolitical entity	NUTS code	NUTS Level	Year of NUTS classification	Area in hectares, 2013	Area in hectares, 2010	Area in hectares, 2007	Area in hectares, 2005
United Kingdom	South Yorkshire	UKE3	NUTS 2	2006, 2010, 2013	Data deficient	1,640	4,430	5,480
United Kingdom	West Yorkshire	UKE4	NUTS 2	2006, 2010, 2013	Data deficient	600	2,340	2,850
United Kingdom	Derbyshire and Nottinghamshire	UKF1	NUTS 2	2006, 2010, 2013	Data deficient	4,890	13,560	16,350
United Kingdom	Leicestershire, Rutland and Northamptonshire	UKF2	NUTS 2	2006, 2010, 2013	Data deficient	7,680	21,470	26,900
United Kingdom	Lincolnshire	UKF3	NUTS 2	2006, 2010, 2013	Data deficient	11,960	37,000	45,150
United Kingdom	Herefordshire, Worcestershire and Warwickshire	UKG1	NUTS 2	2006, 2010, 2013	Data deficient	7,140	20,870	25,840
United Kingdom	Shropshire and Staffordshire	UKG2	NUTS 2	2006, 2010, 2013	Data deficient	4,690	13,750	18,520
United Kingdom	West Midlands	UKG3	NUTS 2	2006, 2010, 2013	Data deficient	220	680	900
United Kingdom	East Anglia	UKH1	NUTS 2	2006, 2010, 2013	Data deficient	24,040	66,240	81,940
United Kingdom	Bedfordshire and Hertfordshire	UKH2	NUTS 2	2006, 2010, 2013	Data deficient	4,930	10,990	13,990
United Kingdom	Essex	UKH3	NUTS 2	2006, 2010, 2013	Data deficient	5,310	14,450	18,560
United Kingdom	Inner London (NUTS 2010)	UKI1	NUTS 2	2006, 2010	Data deficient	0	0	0
United Kingdom	Outer London (NUTS 2010)	UKI2	NUTS 2	2006, 2010	Data deficient	260	1,030	850
United Kingdom	Berkshire, Buckinghamshire and Oxfordshire	UKJ1	NUTS 2	2006, 2010, 2013	Data deficient	9,690	21,940	28,010
United Kingdom	Surrey, East and West Sussex	UKJ2	NUTS 2	2006, 2010, 2013	Data deficient	4,120	11,210	13,710
United Kingdom	Hampshire and Isle of Wight	UKJ3	NUTS 2	2006, 2010, 2013	Data deficient	4,740	12,270	15,040
United Kingdom	Kent	UKJ4	NUTS 2	2006, 2010, 2013	Data deficient	4,970	10,930	12,520
United Kingdom	Gloucestershire, Wiltshire and Bristol/Bath area	UKK1	NUTS 2	2006, 2010, 2013	Data deficient	8,570	21,750	28,550
United Kingdom	Dorset and Somerset	UKK2	NUTS 2	2006, 2010, 2013	Data deficient	3,700	11,450	14,710
United Kingdom	Cornwall and Isles of Scilly	UKK3	NUTS 2	2006, 2010, 2013	Data deficient	1,960	6,360	8,120
United Kingdom	Devon	UKK4	NUTS 2	2006, 2010, 2013	Data deficient	2,470	8,760	11,330
United Kingdom	West Wales and The Valleys	UKL1	NUTS 2	2006, 2010, 2013	Data deficient	340	610	420
United Kingdom	East Wales	UKL2	NUTS 2	2006, 2010, 2013	Data deficient	360	640	390
United Kingdom	Eastern Scotland	UKM2	NUTS 2	2006, 2010, 2013	Data deficient	7,670	31,260	8,440
United Kingdom	South Western Scotland	UKM3	NUTS 2	2006, 2010, 2013	Data deficient	1,200	2,790	460
United Kingdom	North Eastern Scotland	UKM5	NUTS 2	2006, 2010, 2013	Data deficient	5,560	15,450	4,140
United Kingdom	Highlands and Islands	UKM6	NUTS 2	2006, 2010, 2013	Data deficient	2,830	8,970	3,820
United Kingdom	Northern Ireland (UK)	UKN0	NUTS 2	2006, 2010, 2013	Data deficient	270	1,960	2,350

4.5 Summary statement

Incorporating a fallow period into a crop rotation allows agricultural soil to regain moisture (Gao et al., 2014) and has the potential to reduce the population size of crop pests such as nematode worms (Rhoades and Forbes, 1986). Planting non crop plant species on fallow land has the potential to increase the fertility of soils, whilst providing a potentially useful by-product as a result. For example, planting the tree species *Acacia polyacantha* and *Gliricidia sepium* on fallow land in Tanzania has been shown to double following maize yields compared to natural fallow, with the added potential benefit of a fuelwood harvest during the fallow period (Kimaro et al., 2008). It has been suggested that planting camelina during fallow periods has the potential to provide the same benefits to wheat crop yields as traditional fallowing (i.e. increasing soil moisture, reducing disease potential and improved fertility of the soil) whilst allowing farmers to benefit from increased revenue from the camelina harvest (Shonnard et al., 2010). In addition, camelina has low moisture and low nutrient requirements, making it especially suited as a fallow crop in dryland regions (Shonnard et al., 2010) where moisture is naturally limited.

Biofuel crops have the potential to cause detrimental dLUC and iLUC if implemented irresponsibly (Gawel and Ludwig, 2011; Schoneveld et al., 2011). Using fallow land for biofuel crop plantations provides a novel way of minimising the potential negative land use impacts of biofuels by utilising land that is already in agricultural rotation, and by avoiding conflict with food crops through temporal alignment with an established fallow-cropping regime. Whereas fallow land may have been omitted from modelling techniques for forecasting biofuel crop yields in the past (Langeveld et al., 2014), the recognition that arable land has the potential to increase biofuel output without negatively compromising current agriculture practices suggests that fallow land should be considered more seriously as utilisable land for biofuel crop production.

5 Abandoned land in EU

5.1 Definition of abandoned land

Land abandonment is defined as the cessation of active management on agricultural land where there is no intention to return the land to production. This differs from fallowing, as there is no planned recommencement of management. This definition can be used to cover arable, pastoral and arboreal land uses, however most literature and statistics focus upon arable farmland. Due to localized and discipline-specific interpretation, there is no standard accepted definition on when land can be considered abandoned.

5.2 Background

Agriculture is the largest single anthropogenic land-use occupying roughly 40% of the Earth's ice-free surface, an increase of 154 million hectares (~3%) since 1985 (Ellis and Ramankutty, 2008, Foley et al., 2011). Whereas growth has continued in recent years, this has primarily accrued in tropical regions, with temperate zones observing a reduction in agricultural area (Gibbs et al., 2010, Ramankutty and Foley, 1999). This reduction has been caused by an escalation in the abandonment of cropland and pastures (Cramer et al., 2008). Defining and quantifying agricultural abandonment is a complicated process, with a number of definitions and estimates. This confusion arises due to the dynamic nature of the abandonment process. As abandoned land is not a land cover as such, but rather a process of conversion from a managed to an unmanaged state. This means that quantification needs to monitor the change from a baseline period. Furthermore, abandonment can be a temporary situation, as in regions of low productivity cyclic land-use patterns of disuse and re-cultivation are employed (Dutrieux et al., 2016).

Ecologically, the removal of land management restarts ecological successional processes. Depending upon the local climate, soil, and previous usage this may entail a progression to shrub land and eventually forest, or alternatively to natural grassland (Cramer et al., 2008). These transitions can result in a range of consequences. Succession generally incurs positive effects such as increases in carbon sequestration and biodiversity (Martin et al., 2013, Kurganova et al., 2014). However, wildfire occurrence, soil erosion, and water quality can also be negatively affected (Stanchi et al., 2012, Moreira and Russo, 2007).

Formerly agricultural areas represent a considerable land resource in many nations. As these lands have previously been exploited they are unlikely to match the biodiversity or carbon stocks of primary undisturbed habitats, without considerable time (Martin et al., 2013, Gibson et al., 2011).These areas may therefore be highly suitable for re-cultivation, providing additional land whilst maintaining primary habitats and not impacting food productions. Thus, abandoned agricultural land is classified as having low indirect land use change (iLUC) potential, as development in these areas is unlikely to incur downstream land use changes. Low iLUC areas are the primary targets for increased biofuel productions, therefore understanding the drivers, distribution and dynamics of agricultural abandonment is therefore essential for the assessment of potential fuel crop developments.

5.2.1 Drivers of Agricultural Abandonment

The decision to cease production on agricultural land is driven by a range of local, regional, and global drivers. Local factors may include the productivity of land, determined by the soil and climate of the locality. Regional and global drivers relate to political and economic motions that can affect the profitability of farming.

In recent decades, the major drivers of agricultural abandonment have been large-scale political developments. The largest of which was the collapse and subsequent dissolution of the Soviet Union and socialism in Eastern Europe. This breakup removed the state support for agriculture in the form of fixed prices for inputs such as fertiliser, and guaranteed markets for products. This sudden transition to free market economics, combined with uncertainty in land tenure and trading caused major shocks to the agricultural sector. However, adaptation to independent statehood was not uniform across the former Soviet states, these contrast offer a unique opportunity to observe the contribution of national and local scale drivers on land abandonment.

The role of national policies, and in particular land tenure, can be seen by cross border comparisons of newly independent states (Kuemmerle et al., 2006). Poland maintained a degree of private ownership of farmland throughout the socialist period. Accordingly Polish agriculture was well placed to adapt to a free market model, and demonstrates relatively low levels of abandonment (Alcantara et al., 2012, Prishchepov et al., 2012). Conversely, in the Baltic states (Latvia, Lithuania, and Estonia) and Romania land titles were resituated to the heirs of pre-Soviet owners who may have been moved from the area. The absence of land trading mechanisms prevented the sale of this newly redistributed land to potential farmers, these factors combined to produce relatively high levels of abandonment (Kuemmerle et al., 2008, Prishchepov et al., 2012, Nikodemus et al., 2005). The highest levels of abandonment occurred within European Russia, in particular oblasts (regions) bordering Belarus (Schierhorn et al., 2013, Alcantara et al., 2012). This can be attributed to a 90% drop in agricultural subsidies from 1991-1998, followed by the Russian financial crisis of 1998.

The role of local factors can be seen by the patterns of land abandonment within nations. During the Soviet era many farms were operated with a view to increase self-sufficiency and provide employment. Consequently, these facilities were ill suited to competing in a free market economy. In European Russia, a combination of four factors were found to reliably predict abandonment; grain yield in the 1980s, distance to nearest settlement with over 500 people, distance from forest edge, and occurrence within forest matrix (Prishchepov et al., 2013). These variables broadly represent market principles that more isolated and less productive enterprises will fail first. Similar trends were observed in Romania, where unfavourable topography and isolation were strong predictors of abandonment (Muller et al., 2009). The influence of broad-scale regional productivity factors can also be observed. The highly productive Pontic–Caspian steppe in southern Ukraine and Russia displays very low abandonment when compared to comparable northern regions (Alcántara et al., 2013). However, care must be taken with generalizations over local drivers of land abandonment. In western Ukraine and in Albania, productive lowland farms were more likely to be abandoned than less productive upland areas (Baumann et al., 2011). This was attributed to the increase in small scale subsistence agriculture that was isolated from market forces, whereas for-profit farmland failed to prosper and was abandoned (Baumann et al., 2011, Kuemmerle et al., 2006, Müller and Sikor, 2006). Furthermore, isolated villages are less likely to suffer from rural-urban migration in times of economic hardship, and thus retain a labour base (Müller and Sikor, 2006).

5.2.2 Limitation to the utilization of abandoned land

The potential of abandoned land as a resource for biofuel, or food crop, developments has received considerable attention in recent years. As previously discussed, there is consensus that there is a large quantity of abandoned agriculture. The utilization of this land is seen as beneficial of land-use change. As the land is not currently in use, there should be minimal *indirect* land-use change impacts, as there is no usage being displaced. Furthermore, the development of previously exploited areas will preserve the status of the remaining virgin habitats, such as tropical rainforests, which are indispensable for carbon storage, biodiversity, and climate change mitigation. However, not all abandoned land can, or should, be cultivated. Many areas have severe environment, economic, or social limitations to development. Consideration of these factors is essential when evaluating the potential of abandoned land as a resource for future developments.

Environmental conditions may render abandoned land an undesirable re-cultivation option, due to the potential for ecological succession to occur. The cessation of land management will allow the recommencement of natural ecological processes, such that many regions will revert to shrub lands and eventually forests. In Eastern Europe, land abandoned during the fall of the USSR has had up to 25 years of minimal-no management. Accordingly, it is estimated that 10-15% of this land has reverted to temperate forest. Forested land is undesirable for biofuel developments as it is a high land-use change category, and possesses high biodiversity and carbon value. Furthermore, concern must be taken to access the biodiversity value of land where successional processes have not occurred but regional conditions have made the land of ecological value for species.

Economic constraints also need to be considered when evaluating the potential of abandoned land as a resource. As discussed in above, it is inevitable in many regions land was initially abandoned due to low productivity and poor suitability for agriculture. Thus, many abandoned farms are unlikely to be productive for future development, without considerable investment. This is likely to be particularly relevant when non-native or newly developed crops are considered. Furthermore, certain abandoned areas, that were sufficiently productive, will no longer have the necessary infrastructure they require. Abandonment of irrigation systems in dryland regions, or of drainage facilities in wetland bog areas, will render land unsuitable prior to the re-development of this infrastructure.

Land use dynamics are not static, but rather operate continually. Thus, many plots of abandoned land have already been cultivated. The expansion of the European Union by the addition of the 2004 ascension ("A10") nations (Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia) in 2004, and of Romania and Bulgaria in 2007, have increased this trend. Many of the newly ascended nations possess(ed) large areas of abandoned agriculture, access to EU subsidies and markets made some of this land more economically viable. As agriculture is now operating under free-market principles in Eastern Europe, re-cultivation has been focussed on land that is closest to urban centres or highest in productivity. Re-cultivation processes and distribution has received considerably less academic attention than abandonment, therefore estimates and understanding remains limited. In the Ukraine estimate of recultivation range from 170,800 ha to 978,800 ha, depending upon the definition; lower estimates define recultivation as usage in 5/6 years, higher 3/6. Yet the distribution of this uptake was highly uneven. In southern steppe regions, possessing highly fertile black chernozems soils nearly all (up to 69%) abandoned land was re-established.

Land abandonment is not just an economic process, but also a social issue. Large-scale abandonment often coincides with overall economic depression, leading to low employment opportunities. These factors can combine to drive rural-urban migration whereby residents will move to urban areas where employment opportunities are perceived as more available. This process is more likely to affect younger working age persons. If the economic situation continues, the working age population of rural areas can decline considerably. This will have a detrimental effect on the potential recultivation of land in affected area as the potential labour source is compromised. This issue has been observed both in Eastern Europe, where the possibility of European migration became possible, and in the arid regions of Spain.

5.3 Quantifying Agricultural Abandonment

Mapping the distribution of abandoned land can be convoluted, due to varying definition and periods considered. The information and figures presented here should therefore be interpreted according to the criteria and specification of the data used.

Method A presents an assessment of abandoned land for the EU based on the best available evidence within the Eurostat database. This has been undertaken at both national and NUTS-2 levels.

Method B presents a summary of large-scale studies that have utilized remote sensing data to infer agricultural abandonment. These are supplemented with a preliminary study in south east Spain, an area of interest to the ITAKA project.

5.3.1 Method A: Eurostat Data: Utilized Agricultural Area (UAA)

No nation currently collates data on the abandonment of agricultural land. Therefore, abandonment must be inferred from other agricultural statistics. For the EU, the main dataset on agricultural area is the Utilized Agricultural Area (UAA), which reports NUTS2 and national scale statistics on both the number and total area of farmland. For this section, data from the Eurostat table "Key variables by legal status of holding, size of farm (UAA) and NUTS 2 regions-2007" (Code: ef_ov_kvaa) was used; this covers the 1990-2007 period (Figure 23). Using the UAA data as a long-term record is however complicated. Not all nations or NUTS2 areas have consistently reported figures; furthermore, the geographic boundaries of some regions have changes over the time-series. To overcome this issue, the maximum value for the 1990-2005 period was calculated based on the available data. This maximum value was then compared to the 2007 value, to provide an indicative value for agricultural abandonment (Figure 24).

Note: Figures for Portugal include Madeira and the Azores. Figures for France include French Guiana, Guadeloupe, Martinique, and Réunion. No data is available for the French territories of Mayotte or Saint Martin, as they were not independent units during the 2007 census.

5.3.1.1 National-Level Land Abandonment Assessment

The data in Figure 25 show that Mediterranean nations (Spain, Portugal, and Italy) have experienced the most dramatic and consistent declines in agricultural area. This was expected given limited profitability, outwards migration and the decline of traditional farming methods for semi-arid regions. The increases in UAA certain Eastern European nations (Estonia, Bulgaria, Poland and Latvia) may appear to contradict earlier statements concerning widespread abandonment across this region. However, this discrepancy is due to the time periods considered. Most abandonment in Eastern Europe occurred between 1989 and 1993, immediately following the cessation of socialism. These nations only began contributing data to Eurostat in preparation for the 2004 ascension. Thus, the UAA data shows increases following the increased trade to EU nations and improved land tenure conditions occurring in more recent years.

The total cumulative decrease in UAA reported by nationally aggregated statistics is 6775.45 Kha, or -3.8% from the maximum UAA. This figure is pureley indicative as aggregated statistics are not an ideal mechanism for quantifying agricultural abandonment. For example, if in a single NUTS2 area 20 ha of farmland is abandoned and the next year 20 ha of new farmland is created in a different location the change in UAA is zero. Therefore caution should be taken the use of these statistics for planning purposes.

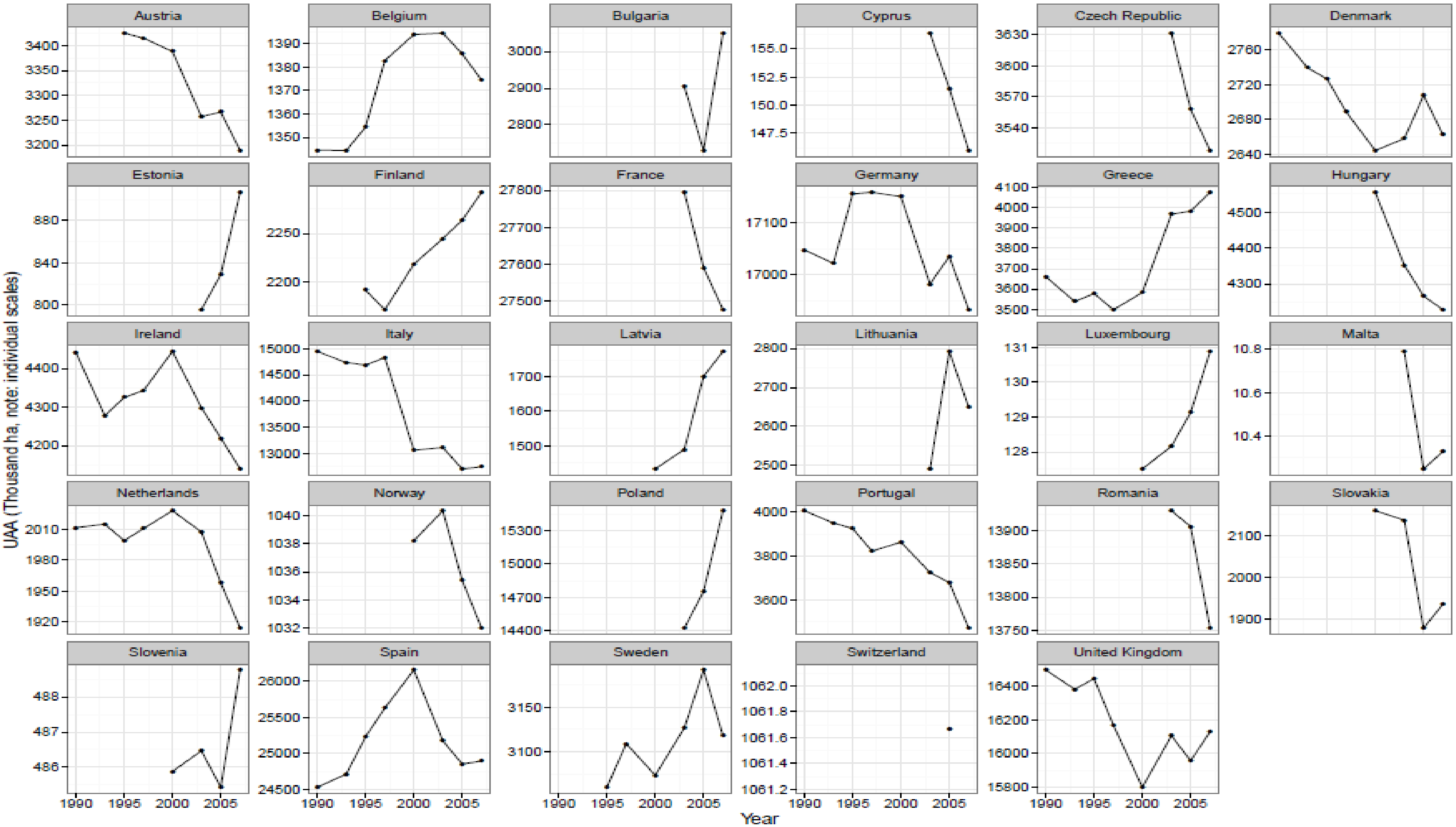


Figure 23. Time series of Utilized Agricultural Area of EU nations plus Norway and Switzerland. Source: Eurostat.

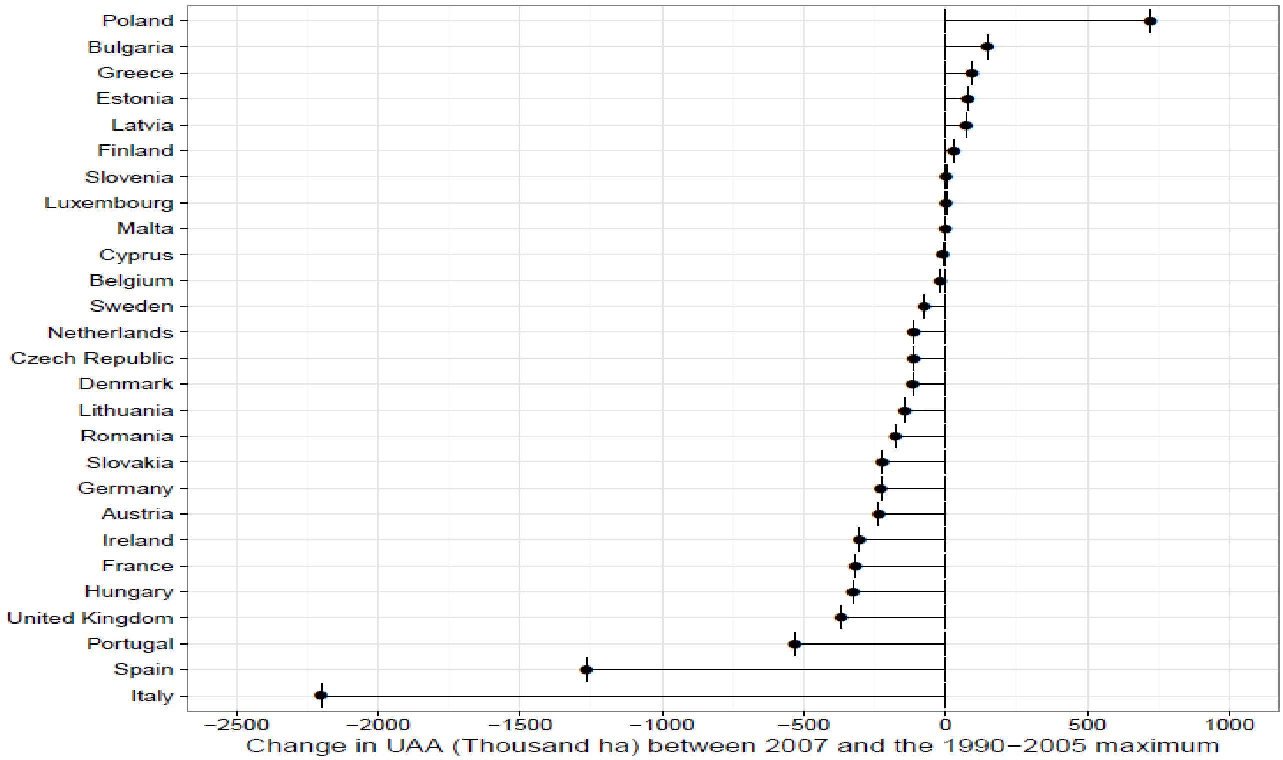


Figure 24 National level change in UAA between the 1990-2005 maximum and 2007

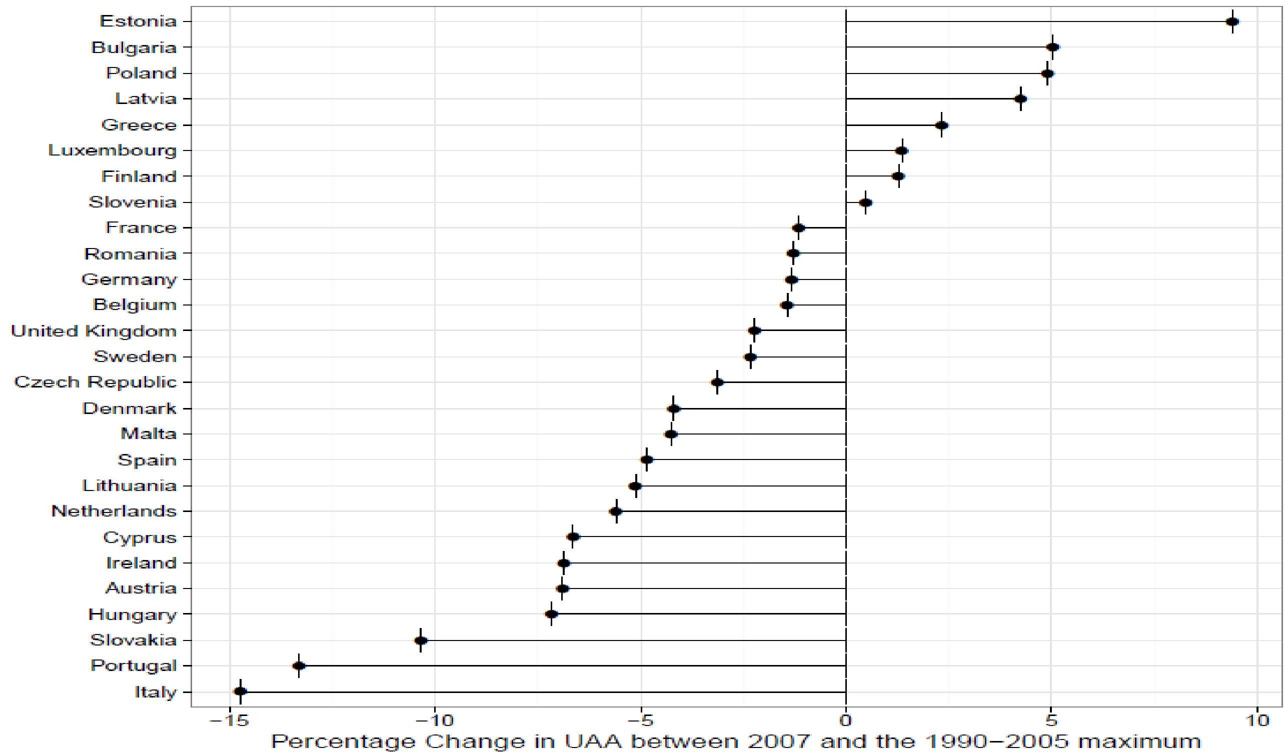


Figure 25 National level percentage change in UAA between the 1990-2005 maximum and 2007.

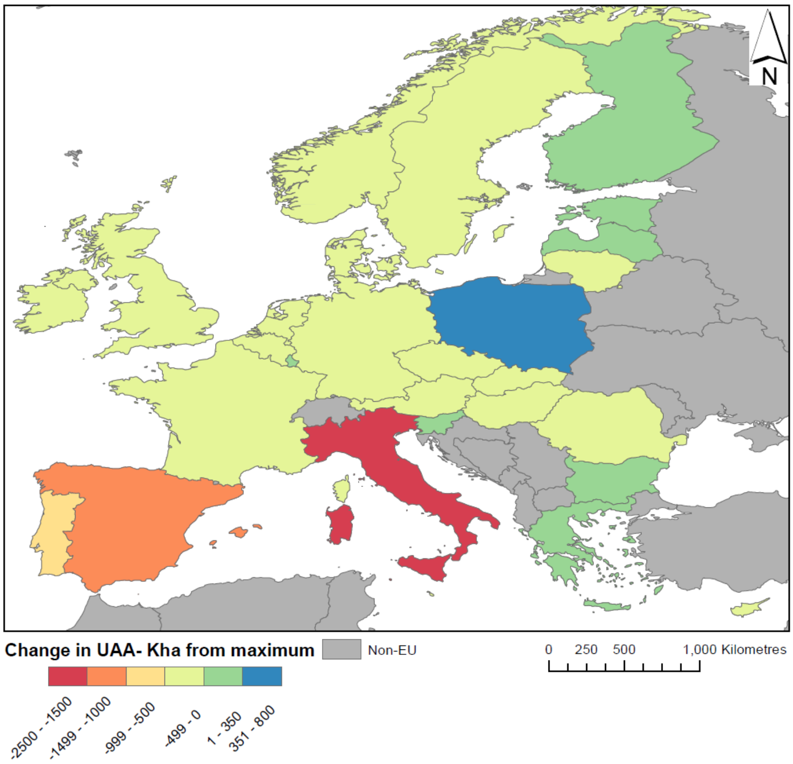


Figure 26. Map of national level change in UAA between the 1990-2005 maximum and 2007.

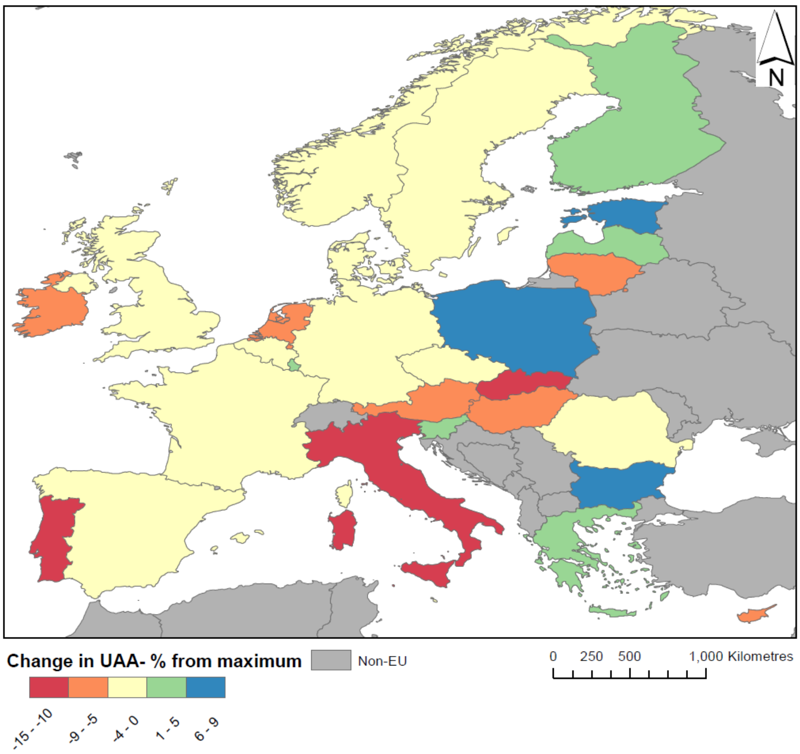


Figure 27. Map of national level percentage change in UAA between the 1990-2005 maximum and 2007.

5.3.1.2 EU28 NUTS-2 level Land Abandonment Assessment

The data presented Figure 28 and Figure 29 shows the NUTS-2 level change in UAA between the 1990-2005 maximum and 2007, as both percentage and absolute change. The overall patterns are comparable to those shown in the national level assessments. The largest reductions in UAA are seen in southern Europe, in particular Spain, Italy and Portugal.

In Spain and Portugal, all regions with the exception of Galicia, Cataluña and La Rioja show major reductions in agricultural area. These areas with increases in UAA can be explained by either relatively high rainfall in the case of Galicia, or developed irrigation for Cataluña and La Rioja. Otherwise, a relationship between increasing aridity and UAA reductions can be observed. This reduction has been reported elsewhere (see Background section) and relate to the decline of traditional agriculture, outward migration from rural areas, and the limited profitability of dryland farming. The areas showing increasing in UAA are removed from these factors due to a more productive climate and greater irrigation and mechanization.

Reductions in UAA for other Mediterranean nations such as France and Italy were also expected due to the adjustments in the CAP leading to decreased farming on marginal lands. Increases in farmlands for eastern Europe correspond to EU accession and improved market conditions following extended periods of low productivity.

The total cumulative decrease in UAA reported by NUTS2 aggregated statistics is 8810.85 Kha, or -4.87% from the maximum UAA. This figure is higher both in value and percentage terms that the figures reported at the national scale. This difference can be atributed to the increases aggregation at the national scale smoothing the data.

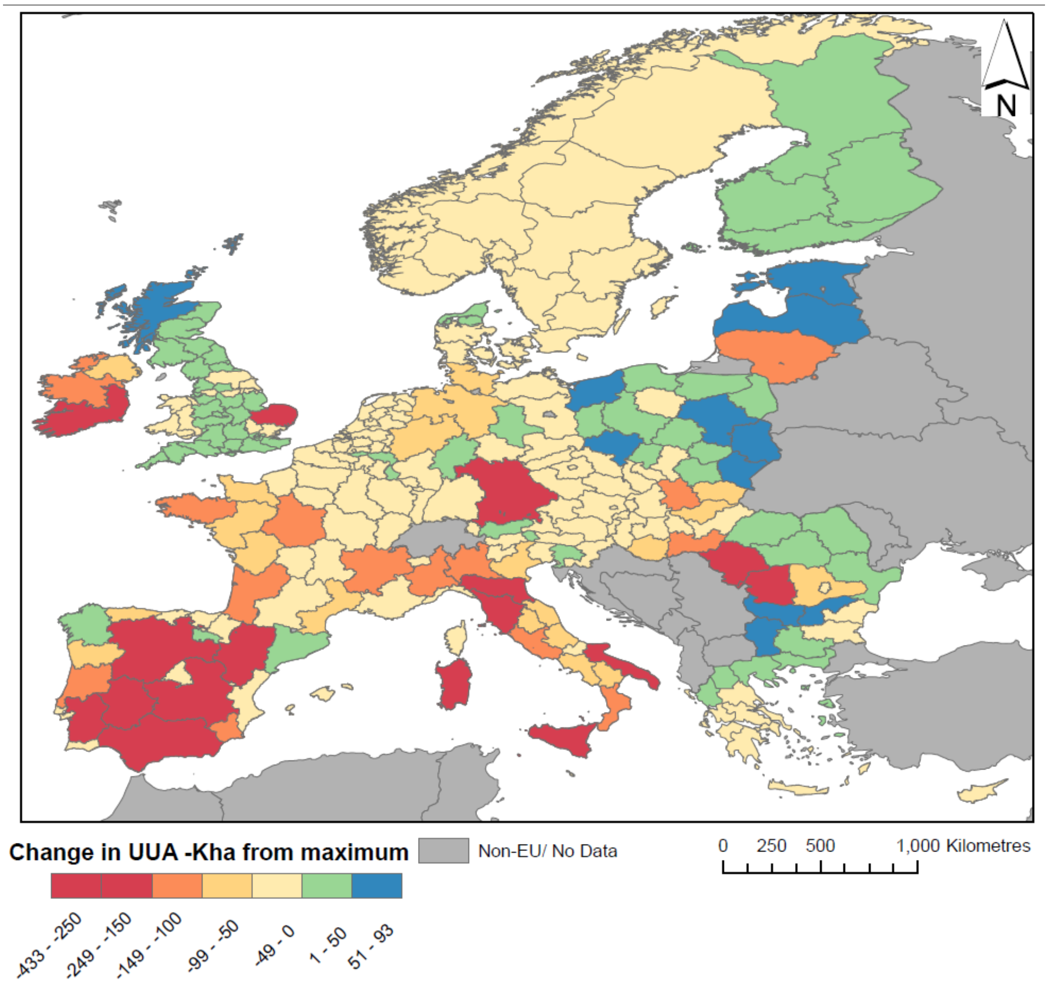


Figure 28. Map of NUTS2 level change in UAA between the 1990-2005 maximum and 2007.

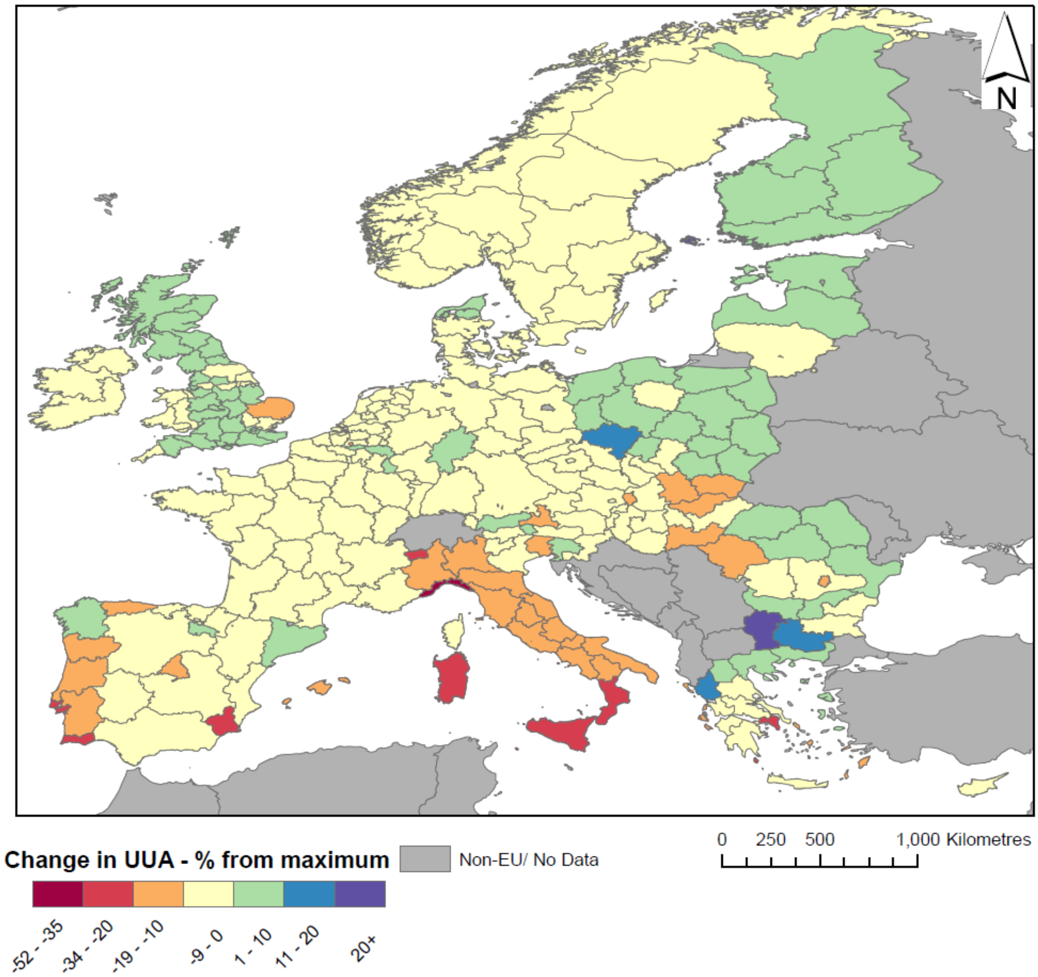


Figure 29. Map of NUTS2 level percentage change in UAA between the 1990-2005 maximum and 2007.

5.3.2 Method B: Identification of abandoned land from remote sensing

The absence of spatially and temporally consistent statistics on land abandonment makes remote sensing-based analysis a candidate choice. A large number of studies have focussed on mapping abandonment, and recultivation, patterns in Eastern Europe with Central and Western Europe receiving comparably less attention.

Section B.1 presents summary of studies that have investigated large-scale abandonment dynamics. Although many studies have been performed at smaller scales, only large-scale studies are presented here as studies of this type allow a consistent interpretation of results.

5.3.2.1 B.1 Summary Of Large-Scale Remote Sensing Studies.

5.3.2.1.1 Eastern Europe and Central Asia.

Alcántara et al. (2013) mapped abandonment across Eastern Europe using remote-sensing data from the Moderate-Resolution Imaging Spectro-radiometer (MODIS) sensor. Using the phenological (seasonal) profiles of vegetation index time-series data it was possible discriminate between active agriculture, forest and abandoned agriculture, with a high degree of agriculture. Figure 30 displays the results of this analysis, with Figure 31 presenting the data aggregated to administrative units. Whereas this study produced highly accurate results, the spatial scale of MODIS data (250 m) may limit detection of smaller scale events, thus presenting a conservative estimate of total abandonment.

In total Alcántara et al. (2013) identified 52.5 Mha of abandoned agriculture, with 32 Mha located in Russia. Cross-border comparisons reveal that the socio-political factors were the primary driver of abandonment, with agricultural suitability being a poor predictor of farmland continuity.

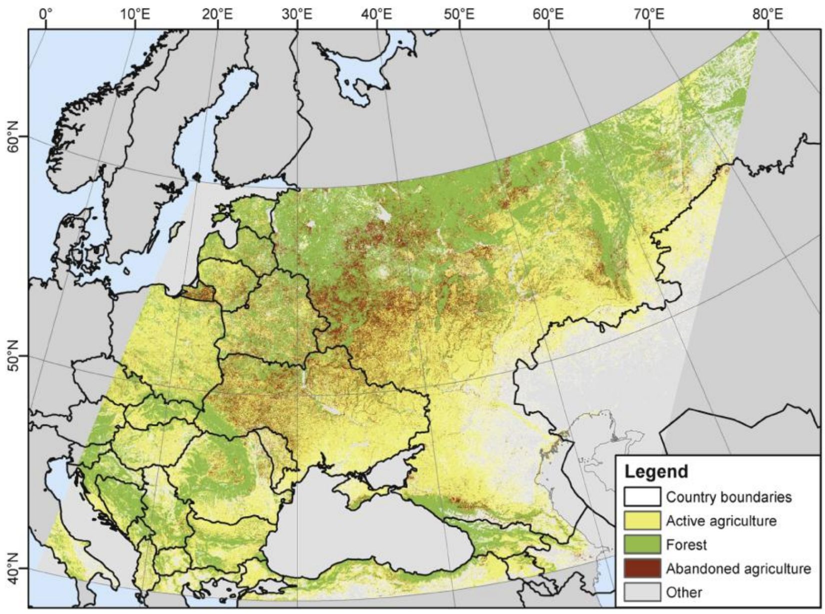


Figure 30. Distribution of abandoned farmland in Eastern Europe and Central Asia from Alcántara et al. (2013).

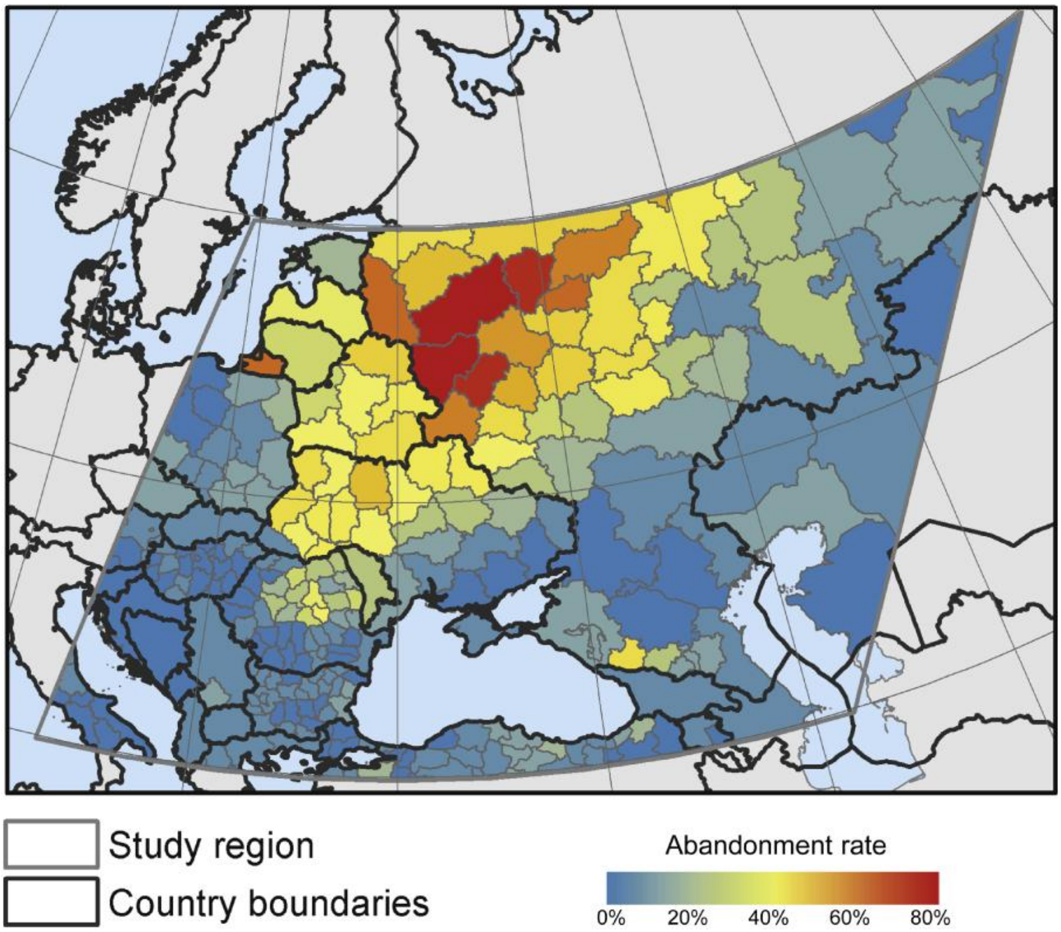


Figure 31. Relative rates of abandoned farmland in Eastern Europe and Central Asia from Alcántara et al. (2013).

5.3.2.1.2 Carpathian Ecoregion

Griffiths et al. (2013b) analysed land cover changes in the Carpathian Mountain Ecoregion (Figure 32) from 1985-2012. This time period considers both the fall of the USSR and the accession to the European Union. The Carpathian region is a mountain arc positions in central-eastern Europe bordering Poland, Ukraine, Romania, Hungary and Slovakia. As shown in Figure 33, the fall of communism resulted in widespread abandonment of farmland. However, the usability of this land for new developments in uncertain. As reforestation and recultivation have occurred over the past 25 years. The relative rates of abandonment and recultivation are strongly influenced by the national political and economic policies. This can be seen in the cross border changes in land cover dynamics.

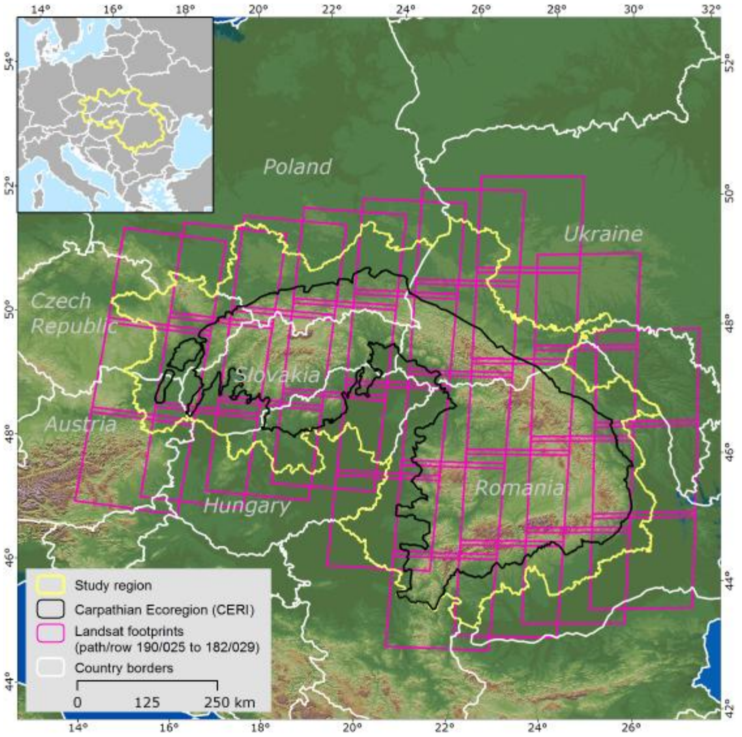


Figure 32. Study location for the Griffiths et al (2013) study.

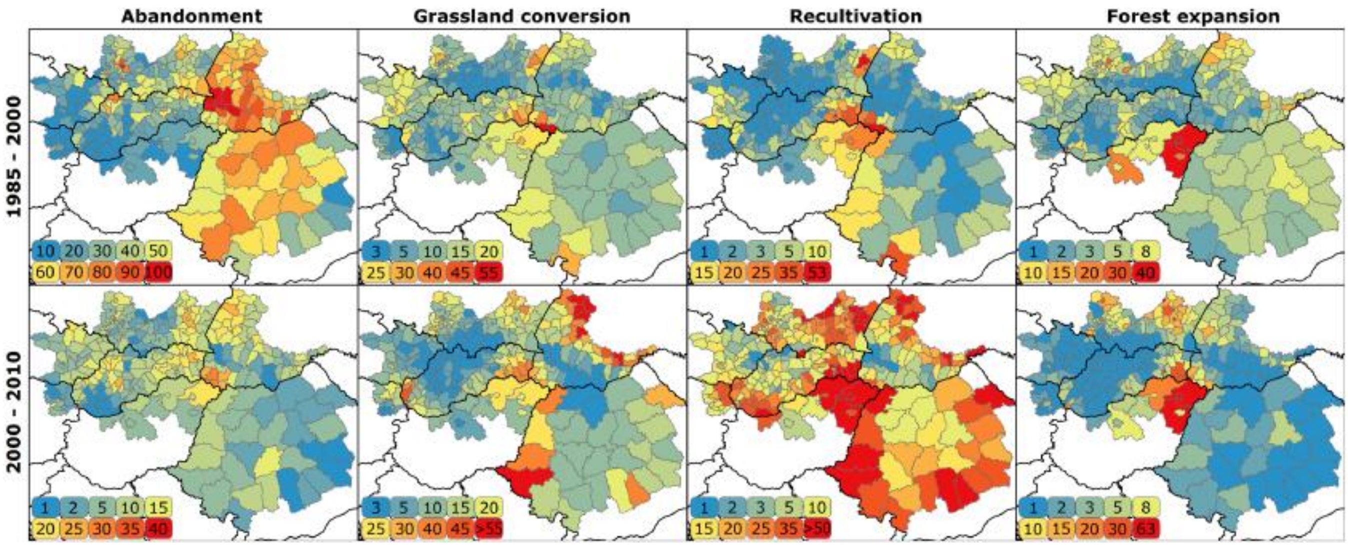


Figure 33. land cover dynamics in the Carpathian Ecoregion over two temporal epochs. From Griffiths et al (2013).

5.3.2.2 B.2 Preliminary Assessment of Land Abandonment in South Eastern Spain, Using Remote Sensing.

In the absence of standardized data on agricultural abandonment, Earth-observation-based assessments are a candidate monitoring choice. The Landsat series of satellites are particularly well suited for observing land cover change processes, due to appropriate spatial and spectral resolutions, combined with a near 40 year long archive of data (Kennedy et al., 2014, Roy et al., 2014). Land cover change detection using Landsat data has traditionally operated on a bi-temporal basis, by comparison of land cover at two or more temporal epochs. This approach has been implement for mapping land abandonment in a range of regions, including, Eastern Europe, Russia, and the USA (Jönsson and Eklundh, 2004). Recent advances in large-area mapping have allow high-resolution analysis to be applied on national or regional scales (Griffiths et al., 2013a, Griffiths et al., 2013c, Roy et al., 2010, Hansen et al., 2011). However, Landsat-based mapping in a consistent, large-area, context remains challenging due to a number of issues. In many areas the Landsat archive is incomplete, due to a combination of data archive policies and cloud cover, there may be long periods with no or insufficient data. This is particularly limiting for agricultural mapping, which regularly requires multiple images per year (Jönsson and Eklundh, 2004). Furthermore, cyclic land use practices, such as fallowing, may result in the misclassification of abandonment.

An attempt to minimise the issues of bi-temporal change detection, is seasonality metrics classification. Seasonality metrics are a measure of the change in vegetation over the year as seasons progress, most commonly quantified using the Normalized Difference Vegetation Index as a proxy for biomass. Different land cover types display widely divergent seasonalities, allowing these metrics to be employed as classification variables. Alcantara et al. (2012) demonstrated that seasonality metrics were capable of detecting forest regrowth on abandoned agriculture in the Baltic region, this was achieved by using Landsat-derived land cover change maps as training data. This approach was later extended to cover Eastern Europe and large sections of Russia, offering a large-scale analysis that would not be possible with Landsat data alone (Alcántara et al., 2013).

This study presents analysis attaining to map agricultural abandonment, for a region of Spain (Figure 34). Whereas a number of studies have reported on land abandonment processes in Spain (Suárez-Seoane et al., 2002, Romero-Calcerrada and Perry, 2004, Symeonakis et al., 2007, Corbelle-Rico et al., 2012) , there has been no large-scale assessment. The methodology implemented here is based on the seasonality metrics approach presented by Alcántara et al. (2013), Alcantara et al. (2012). This approach demonstrated good accuracy in Eastern Europe and Russia, but has not been implemented in Mediterranean Environments.

5.3.2.2.1 Methods

The methodology presented here aims to combine the benefits of time-series methods applied on temporally dense, coarse-resolution data, with the long-term monitoring offered by Landsat. This consists of two primary components; firstly, seasonality metrics are extracted from a dense time-series of MODIS-derived NDVI images for the period 2003-2008. Secondly, these metrics are used to classify land cover and land abandonment. This classifier is trained using reference data obtained by comparing Landsat-derived land cover maps from 1984 and 2011. The advantage of this approach is the possibility of wall-to-wall mapping, which is not easily possible using Landsat data, combined with a more rigorous classification for land abandonment.

5.3.2.2.2 Study Area

This study focused on southeastern Spain (Figure 34), covering the Murcia, Valenciana and Castilla-La Mancha regions, roughly 25% of Spain. Land abandonment processes have been documented in the region (Symeonakis et al., 2007), and the climate and land cover can be considered representative of Spain as a whole. The region is characterized by irrigated agriculture on the plains, with olive groves, shrub lands and forest on the raised slopes and hills.

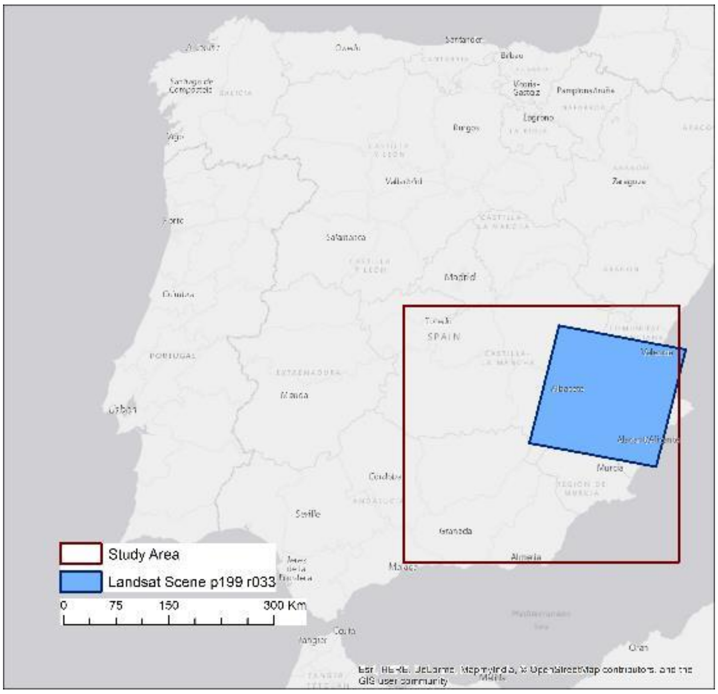


Figure 34. Map of the study location in southeastern Spain, showing the footprint of Landsat scene path 199 row 033.

5.3.2.2.3 Time-series Data

Normalized Difference Vegetation Index (NDVI) images were obtained from the MODIS Terra and Aqua satellite archives, for the period 2003-2008 (products MOD13Q1 and MYD13Q1 respectively). These images consist of 250m, 16-day composite NDVI images, with clouds, atmospheric effects, and snow masked. The final time-series consisted of 45 images per year, totalling 270 images. This time-series was input into the Timesat processing software. Timesat is a suite of algorithms for extracting pixel wise phenological metrics from multi-temporal satellite data (Jönsson and Eklundh, 2004). Firstly, the raw NDVI data is smoothed using an Adaptive Savitzky-Golay filter, to minimise noise within the series. From this smoothed series, 11 seasonality metrics (Figure 35) are extracted based on the relative change in NDVI against time (Eklundh and Jönsson, 2012, Jönsson and Eklundh, 2004).

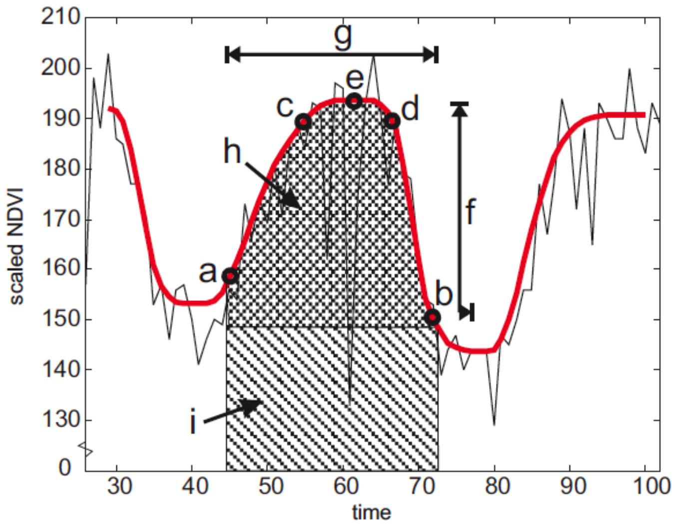


Figure 35. The seasonality metrics extracted by Timesat. Points (a) and (b) mark, respectively, start and end of the season. Points (c) and (d) give the 80 % levels. (e) displays the point with the largest value. (f) displays the seasonal amplitude and (g) the seasonal length. Finally, (h) and (i) are integrals showing the cumulative effect of vegetation during the season. Figure from Eklundh and Jönsson (2012).

5.3.2.2.4 Training Data

Training data for the classifications was obtained from a thematic change detection analysis of Landsat imagery. This required generating Landsat-based land cover maps for 2 temporal epochs, 1984 and 2011, to identify pixels characterising agricultural abandonment. For each epoch, three seasonal composites, winter, summer and autumn, were created. For 1984 this required several images to be included from other years (Table 6), image seasonality is considered more important than year with a three year period for land cover mapping (Griffiths et al., 2013c).

Table 6. Image used for land cover mapping.

Epoch	Season	Day of Image Acquisitions (year if different)
1984	1	17(87), 97(87)
	2	169, 174(86)
	3	233 281
2011	1	35, 90*
	2	179, 107
	3	259, 275, 283, 299

*An overlapping Landsat scene, path 200 row 033, was used due to high cloud cover on scene edge

The annual image composites were classified using a Random Forest model trained with 420 reference points based on high-resolution data captured in 2011/2012, from the ESRI Imagery Catalogue (Pal, 2005). The classes mapped were forest, shrub land, bare soil, cropland and olive groves. Training samples were iteratively resampled to obtain an acceptable accuracy (70% out of bag (OOB) class accuracy). Following the creation of a Random Forest classification model, both epoch composites were classified and a thematic change detection applied.

Identifying agricultural abandonment from thematic change analysis requires careful examination of results. Local land use practices, such as fallowing or rotation grazing, may lead to incorrect mapping of cropland abandonment.

The change detection analysis produced very few pixels as changing from cropland to forest or shrub (0.17 and 0.19%). Therefore, cropland abandonment was not considered widespread and focus was directed at mapping abandonment of olive groves. Due to difficulty in separating olive from shrub land classes, only pixels that had changed from olive to forest were used for classifying abandoned olive groves.

The final classes used for to classify the seasonality metrics were irrigated agriculture, forest, olive groves, shrub land, bare ground and abandoned olive groves. The abandoned olive grove class was trained with Landsat pixels that change from olives to forest, other classes were trained with pixels from the 2011 classification that had an 80% class probability.

5.3.2.2.5 Results: Landsat-Based Landcover Maps

The Random Forest classified produced an out of bag (OOB) class error of 29.06% (overall accuracy of 70.94%). A confusion matrix showing the predicted and actual classes for training samples is shown in Table 7 and the resulting land cover map for 2011 in Figure 36.

Table 7. Confusion matrix for the Random Forest classification, Classes: 1= Irrigated Agriculture, 2= Forest, 3= Olive Groves, 4= Bare Ground, 5= Shrub lands.

		Predicted Class					
		1	2	3	4	5	Class Error
Actual Class	1	33	4	8	0	2	0.298
	2	7	50	1	1	10	0.275
	3	3	3	68	18	13	0.332
	4	0	0	21	56	5	0.317
	5	1	7	5	11	86	0.218

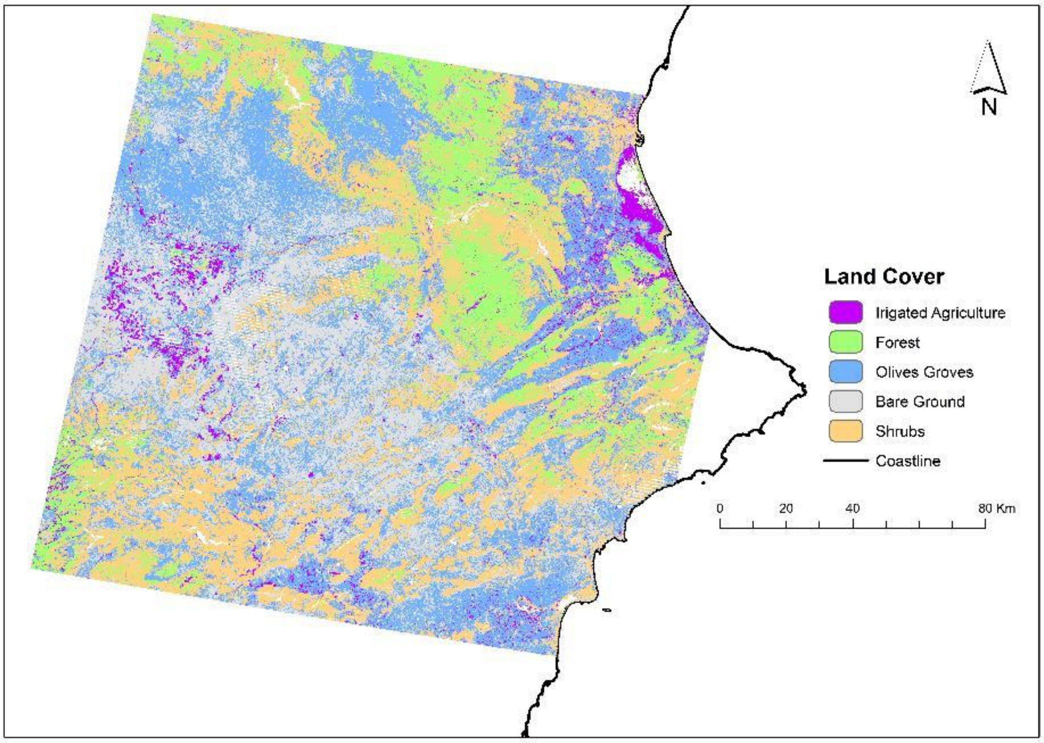


Figure 36. Land cover map for 2011.

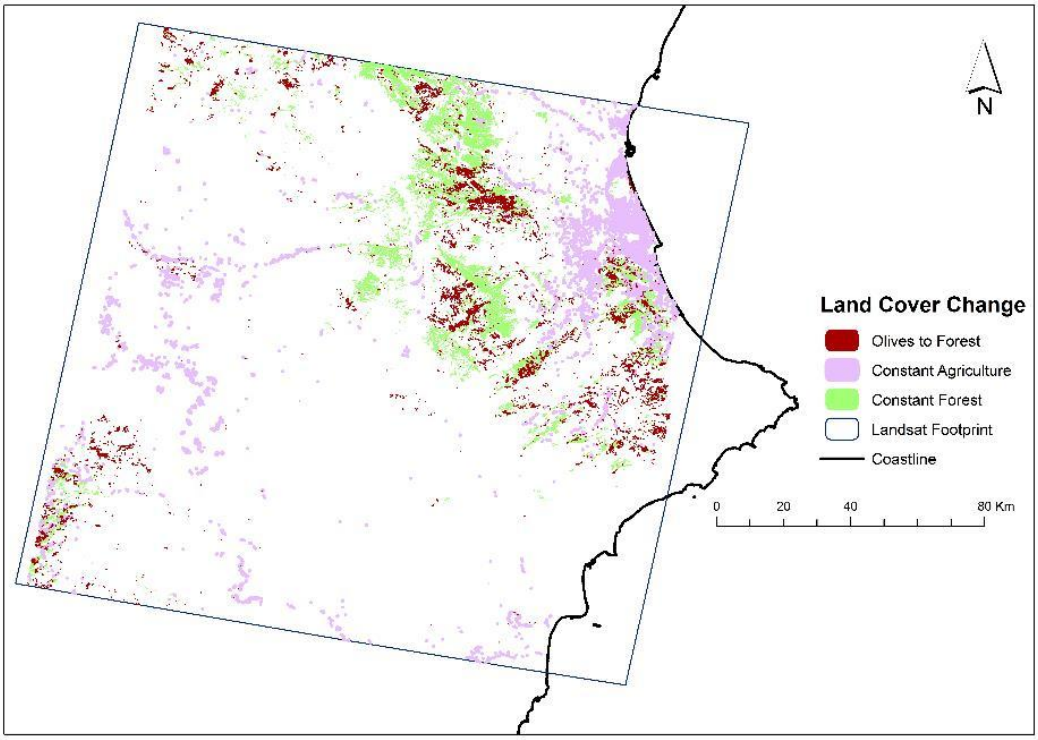


Figure 37. Land cover change and agricultural areas, 1984-2011.

Inspection of the seasonality metrics extracted from Timesat revealed persistent cloud cover for a number of years (2004, 2006 and 2008), these years where therefore excluded from the final classification. The remaining seasonality parameters were classified using a Random Forest model, trained with pixels extracted from the 2011 classification and change detection analysis.

		Predicted Class						
		1	2	3	4	5	6	Class Error
Actual Class	1	243	3	99	1	0	15	0.327
	2	3	217	8	13	11	5	0.156
	3	114	3	190	1	0	37	0.449
	4	1	11	6	194	72	46	0.412
	5	0	16	0	63	331	6	0.204
	6	10	3	27	46	4	261	0.256

Table 8. Confusion Matrix for the final classification, Classes are: 1= Irrigated Agriculture, 2= Forest, 3= Olives, 4=Bare Ground, 5= Shrub land, 6= Abandoned Olive Groves.

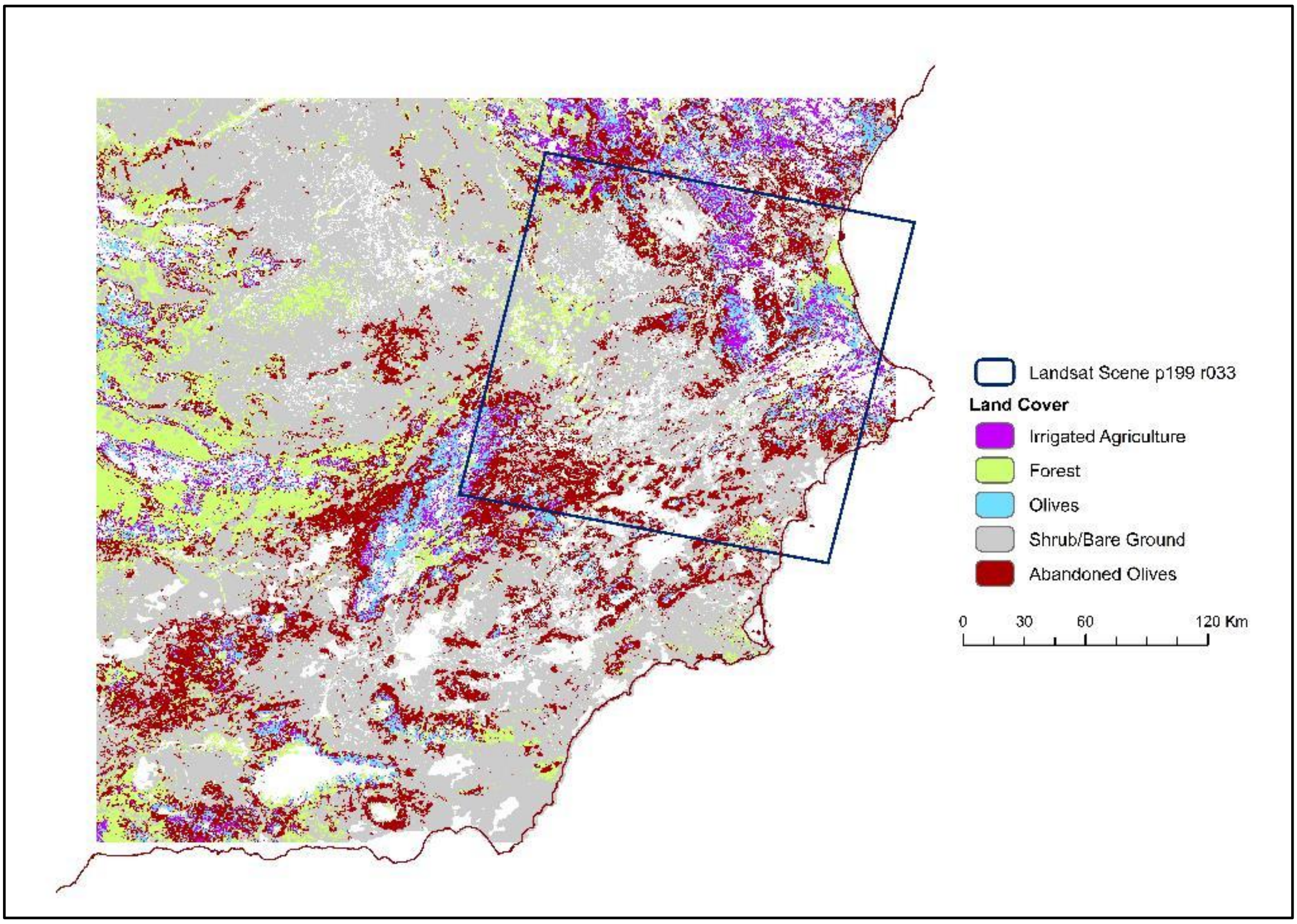


Figure 38. Final Classification of Land Abandonment for 2011.

5.3.2.2.6 Discussion and Conclusions: Land Abandonment in Spain

The final classification of land abandonment, specifically olive groves (Figure 38) produced acceptable accuracies, according to the Random Forest iterative bootstrapping (Table 8). However, it should be cautioned that this accuracy is likely to be spatially auto-correlated, with greater accuracy within the Landsat training area. Overall, 40,981 km^2 was mapped as abandoned (~30% of the study area). Spatially, abandonment was prevalent on forest borders and slopes. This agrees with smaller scale studies, where a migration from traditional olives on terraces, to large-scale cultivation have been highlighted (Romero-Calcerrada and Perry, 2004, Corbelle-Rico et al., 2012).

Land abandonment mapping in Spain, and other Mediterranean counties, presents unique challenges for Earth-observation assessments. Whereas in Eastern Europe, abandonment is characterized by forest regrowth on former cropped fields (Alcantara et al., 2012), in this study olive grove abandonment was more prevalent. This transition is comparably subtle, providing a less distinct seasonal signal, hence the class confusion between abandoned, shrub and olive categories in the final classification. The small scale on which this form of abandonment occurs also present difficulties, these transitions may not be detectable using the 250m resolution MODIS data.

This study adds to research documenting the potential of remote sensing-based analysis for the mapping of agricultural abandonment. However, future work will be required before assessments can be made at an accuracy suitable for policy decisions. The launch of new Earth-observation satellites and sensors, such as Landsat 8 and the EU's Sentinel program, will increase the potential of high-resolution assessments as data coverage and volume increase. An increased volume of high-resolution data would allow accurate annual land cover assessments to be undertaken, thus correcting for a number of issue in the bi-temporal classification of abandonment.

5.4 Summary

A review of published studies combined with analysis of official data, confirms that there is considerable evidence supporting the widespread abandonment of farmland in southern and Eastern Europe. This abandonment generally falls into two categories. In Eastern Europe, the majority of abandonment occurred due to the collapse of the USSR in the early 1990's. This agriculture was comprised of large arable fields. In southern Europe, abandonment is associated with the decline of traditional livelihoods and the limited profitability of dryland farming. These areas are comprised of smaller farms with a large number of olive groves and hillslope terraces. Both of these phenomena should be placed in the context of on-going decreases in agricultural area across developed nations and the temperate regions.

The potential of abandoned land to be used for biofuel production must be assessed on a site-specific basis. Using official statistics regional estimates of abandoned land can be obtained. Using NUTS2 level data it is estimated that there is 8.8 Mha (5.0%) agricultural abandonment, at national scale estimates decrease to 6.8 Mha (3.8%) for Spain. However, these are calculated at an aggregated level, and cannot be used to infer the status of individual farms. Furthermore, the quantity of abandoned land is in continual flux, as farmland is brought in and out of production.

Earth-observation based methods to provide continued monitoring of agriculture have good potential for this area particularly with the increase availability of moderate resolution (<30 m) data from Landsat 8 and Sentinel 2.

The presence of large areas of abandoned land should also be interpreted with caution; many areas may have environmental, economic or social limitation that render them unsuitable for development of any kind, including biofuels. Planned development must take into account the site-specific conditions and limitations that may be present.

6 Contaminated land in EU

Under certain cultivation scenarios biofuels may compete with other land uses such as food production. Furthermore, this competition will only intensify as the demand for biofuels increases and the on-going challenge for the production of biofuels is finding sufficient suitable land on which to grow feedstocks. One option that has generated significant interest and is supported by a number of international organizations including the UN-coordinated Global Bioenergy Partnership is the cultivation of biofuel feedstocks on contaminated and degraded land[15]. Although it should be recognized that these lands are also the target of several other initiatives such as the Bonn Challenge to restore 150 million hectares of lost forests by 2020, or pressures for brownfield sites to be turned over to low carbon infrastructure projects such as wind and solar power. In each case, a range of sustainability indicators must be applied to benchmark outputs from individual projects that recognise and balance the economic, environmental and social components to sustainability.

However, one of the problems with these schemes lies in the wide variation in the definition of 'contaminated', 'degraded', 'polluted' and 'brownfield' land across the EU. This is not entirely surprising given the range of climates, cultures, ecosystems and land uses, and in a practical sense it may be the case that single precise definitions are neither attainable nor desirable. For example, land that is determined as degraded in a traditionally arable farming area may actually be highly valuable to pastoralists, whilst other areas may have significant cultural and social significance. In consequence, creating a policy framework that can realistically take into account all of the issues and yet remain applicable and practical on the ground is a challenging task.

Whilst it is readily accepted that estimating LUC for biofuel crops is at best controversial, with determination of both positive and negative effects difficult at a local level (Gawel and Ludwig, 2011, Van Stappen et al., 2011), an initial assessment of the externalities of growing *Camelina sativa* on chemically degraded land maybe considered favourable. The use of chemically degraded land would allow camelina biofuel production to align with a preventative policy for biofuel production (Di Lucia et al., 2012). Additionally, camelina biofuel grown on contaminated land has the potential to impact positively on food security by using land deemed unsuitable for food production as well as the possible strengthening of the domestic climate mitigation policy through lessening the dependency of the EU on global energy fostering and allied carbon leakage (Gawel and Ludwig, 2011). Although long-term changes in cropping are not anticipated for the production of camelina due to agronomic concerns, care is needed when selecting sites to ensure that biodiversity and water security are not compromised. The prospect of finding viable alternative strategies for chemically degraded land and minimize LUC is one of the key initiatives within the ITAKA project. The question of whether camelina can be cultivated on severely degraded and heavily contaminated land together with an assessment of trace metal uptake and transference into feedstock co-products such as animal feed has been the subject of task 1.2, task 5.17 and the ITAKA sister deliverables D5.7.

6.1 Policy

The European Commission's Directorate General for Energy has expressed a direct interest in developing a policy framework that could be incorporated into the Renewable Energy Directive and incentivize biofuel feedstock production on degraded land. Within this policy it has been determined that a carbon credit bonus allowance of 29 g CO_2eq/MJ shall be applicable to the life cycle analysis for a period of up to 10 years, for biomass feedstocks cultivated on severely degraded or heavily contaminated land[16]. However, this bonus can only be applied provided that

[15] http://www.ieabioenergy.com/wp-content/uploads/2013/09/7280.pdf (Accessed October 2016).

[16] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52010DC0011 (Accessed October 2016).

the land was not in use for agriculture or any other activity in January 2008, can be shown to improve soil carbon stocks, and is compliant with the following EU definitions of severely degraded land and heavily contaminated land:

(a) "severely degraded land" means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded;

(b) "heavily contaminated land" means land that is unfit for the cultivation of food and feed due to soil contamination.

6.2 Assessment of human-induced soil degradation

The United Nations Environment Programme's (UNEP) and International Soil Reference and Information Centre's (ISRIC) Global Assessment of Soil Degradation (GLASOD) project was the first to attempt to assess the extent of soil degradation and underpins subsequent land degradation assessments such as ASSOD[17], FAO World Soil Resources Reports[18], PESERA[19] and SOVEUR[20].

Based on estimates from experts, and at a scale of 1:10 million, GLASOD recognized two main categories of human-induced soil degradation (H-ISD); the first considered processes that recognized the trans-boundary nature of soil degradation, leading to off-site effects, such as water and wind erosion, whilst the second category considered on-site effects and focused on processes such as compaction, sealing, nutrient loss, salinization and pollution (Oldeman et al., 1990a). Degradation was classified as light (some reduction in agricultural suitability); moderate (greatly reduced agricultural production); strong (biotic functions impaired such that it is considered to be non-reclaimable at farm level); or extreme (biotic functions destroyed, non-reclaimable). Severity of degradation was seen as the product of the degree of degradation and the spatial extent. As a result, the global assessment identifies the dominant type of degradation for a region although other vectors of degradation are likely to be operational.

GLASOD determined that soil degradation affected some 23% (219 Mha) of the European land surface: Water and wind erosion were found to be the dominant forces affecting 158 Mha, followed by physical compaction of soils due to heavy machinery affecting 35 Mha, and chemical degradation due to nutrient loss, salinization and pollution affecting 26 Mha. Deeper examination of the data suggests that whilst the area affected by chemical degradation in Europe is consistent with that of area affected worldwide, the main drivers vary considerably: Globally, nutrient losses and salinization are the greatest contributors to chemical soil degradation, but in Europe these two degradation types account for only 27% of chemical degradation (7 Mha). By far the greatest source of chemical soil degradation in Europe is attributed to pollution (19 Mha), an order of magnitude greater than the global assessment (Oldeman et al., 1990b).

More recently, the European Environment Agency state and outlook 2010 Report, known as the SOER 2010 provided a pan-European evaluation on the current state of soil in Europe (EEA, 2010). SOER 2010 identified a number of key processes that threaten soil integrity, including biodiversity decline, compaction, contamination, erosion, landslides, organic matter decline, salinization and sealing. The findings of the recent 2010 SOER assessment show that whilst the effects of such processes are variable across Europe the nature of the threats remain the same

[17] http://www.isric.org/projects/soil-degradation-south-and-southeast-asia-assod (Accessed October 2016).

[18] http://www.fao.org/soils-portal/resources/world-soil-resources-reports/en/ (Accessed October 20160.

[19] http://www.isric.org/projects/pan-european-soil-erosion-risk-assessment-pesera (Accessed October 2016).

[20] http://www.isric.org/projects/mapping-soil-and-terrain-vulnerability-central-and-eastern-europe-soveur (Accessed October 2016).

and in many cases soil degradation processes are accelerating rather than declining (Jones et al., 2012).

Current estimates of EU land degradation due to chemicals tend to be at a local scale, and are hindered through lack of EU regulation, common definition, comprehensive inventories and difficulties in data validation (Jones et al., 2012, Lado et al., 2008).

6.3 Definition of contaminated land

At international level, at EU level, at member state national level and even at regional level there are a number of alternate and slightly different definitions for ‘contaminated land’. Definitions of contaminated land are often built on a risk-based measure with respect to some identified receptor, but this lack of a common definition greatly complicates any assessment or comparison.

In some EU member states, such as Belgium, Bulgaria, Denmark, Poland and Romania, the definition of known or suspected contaminated land is largely synonymous with brownfield land, whereas brownfield sites (i.e. formerly industrial or mining sites) are recognized as not necessary contaminated in other member states such as Germany, Slovenia, UK and Ireland. Nevertheless, there is often significant overlap between these two categorization as exemplified by the following well known international example is the US EPA definition: “With certain legal exclusions and additions, the term ‘brownfield site’ means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant”, although US brownfields legislation is not exclusively based on contaminated land and does also cover classes of non-contaminated land. Hence one land type can be defined as a subset of the other and context is fundamental to the definition, since dereliction and previous land use are particularly important to the classification. However, in most member states policy and regulation around contaminated land emerged prior to its emergence for brownfield land, which suggests a natural hierarchy for land management. The complex relation between different land categorizations is shown as a simplified model in Figure 39 (adapted from a diagram originally prepared by the UK Parliamentary Office for Science and Technology).

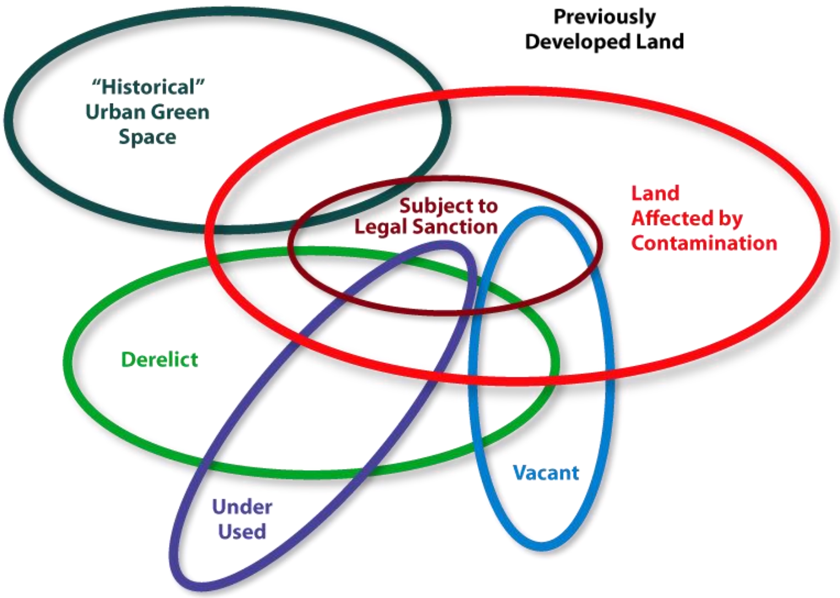


Figure 39. Simplification relation between different land categorization subsets (excludes rural land condition for simplicity).

Because of the variable definitions for contaminated land and the variable data collection methodologies, the data between different EU member states are not readily comparable.

6.4 Data sources: cover and limitations

Since 2001 the European Environment Agency (EEA) and later the EU Joint Research Centre (JRC) has collated survey data on the state of the European environment intended to answer several policy relevant questions such as: What is the estimated extent of soil contamination? How much progress has been achieved in the management and control of local soil contamination? Which sectors contribute most to soil contamination? What are the main contaminants affecting soil and groundwater in and around contaminated Sites? In the latest report (Van Liedekerke et al., 2014), the sixth official data collection and assessment exercise, the National Reference Centres for Soil in 39 countries (EU28 plus cooperating countries) belonging to the European Environment Information and Observation Network (EIONET) were surveyed, with 27 countries returning questionnaires. Estimates of the extent of local soil contamination were available for approximately one third of the countries surveyed with an average of 4.2 Potentially Contaminated Sites[21] per 1,000 inhabitants and 5.7 Contaminated Sites[22] per 10,000 inhabitants. Tentative extrapolation to the whole of Europe by the authors, produces an estimate for the total number of 'potentially contaminated sites' of around 2.5 million, of which 340,000 sites are estimated to be 'contaminated sites' and in need of remediation. These data, based on expert judgement, are broadly comparable to the EIONET 2006 survey in which there were estimated to be 3.0 million potentially contaminated sites, of which 250,000 sites are identified as contaminated and in need of remediation (EEA, 2007), the difference in the figures coming from the application of slightly different assessment methodologies. Furthermore, there are also suggestions that the number of identified sites may be expected to increase by as much as 50% by 2025 (EEA, 2007, EEA, 2010).

Within EIONET 2011 survey, the 27 responding countries have identified a total of 1,170,000 potentially contaminated sites and 127,000 contaminated sites, with 58,000 sites having already been remediated. However, the term potentially contaminated site can be understood differently in different member states, with some countries defining it as those sites identified by mapping potentially polluting activities (e.g. Belgium, Luxembourg, The Netherlands and France) whilst for other countries a more evidence based approach is needed (e.g. Austria, Hungary, Norway). Member state definitions do not necessarily parallel those used by EIONET and so some measure of uncertainty is inherent.

Nevertheless, within this and other EIONET reports (Panagos et al., 2013) there are no specific data on the area of contaminated land within the EU. Whilst an estimate of contaminated land area is discussed in reports such as IEEP 2014 space for energy crops report[23] which quote an estimated 198,642 ha of contaminated land in the EU and cites EIONET 2006 and 2011 reports as the origin of source data, these self-compilations of figures are severely data deficiency and woefully inconsistent. Furthermore, such quantifications are incompatible with other source data and are likely to represent a significant underestimate. For example, the area of contaminated land

[21] The term 'Potentially Contaminated Site' refers to sites where unacceptable soil contamination is suspected but not verified, and where detailed investigations need to be carried out to verify whether there is an unacceptable risk of adverse impacts on receptors.

[22] The term 'Contaminated Site' refers to a well defined area where the presence of soil contamination has been confirmed and this presents a potential risk to humans, water, ecosystems or other receptors. Risk management measures, e.g. remediation, may be needed depending on the severity of the risk of adverse impacts to receptors under the current or planned use of the site.

[23] http://www.ieep.eu (Accessed October 2016).

within the UK is assigned a null value within the IEEP compilation, whereas the UK Environment Agency state there to be over 400,000 ha of contaminated land in the UK[24], and similarly the seemingly detailed information for Romania totalling 25,481 ha of contaminated land are incompatible with correspondingly detailed data from the Romanian Ministry of Environment and Forests National Environmental Protection Agency who state there to be 410,121 ha of contaminated land in Romania[25].

Pragmatically, any estimate of contaminated land area will be subject to significant uncertainty without detailed investigation, since the fundamental concept of a pollutant linkage for the risk-based definition of contaminated land needs to be established to connect pollutant source and receptor through a pathway. Hence the bounds of the contaminate plume are unknown without detailed investigation.

It is apparent that land contamination is a widespread infrastructure problem of varying intensity, significance and risk, which affects the whole of the EU. However, addressing the problem of contaminated land is a comparatively recent concern and so detailed inventories and site mapping are not commonly available. There are no EU scale policy targets for the management of local soil contamination, and although national targets do exist in many member states, the time line for these aspirational targets stretches out many years into the future (see Annex C). Existing estimates of contaminated land area at member state level are often dependent upon expert judgement and so are inherently uncertain, whilst EU scale information is fragmented by a lack of common definition.

6.5 Most frequent contaminant species

For contaminated sites within the EU, the distribution of the different contaminant species is broadly similar for both soil and groundwater. These distributions are illustrated in Figure 40 and show that the main contaminant categories are mineral oils and heavy metals. However the geographic distribution of contaminants is widely variable: Mineral oil contamination is especially dominant in Belgium (~50% of land sites) and Lithuania (~60% of land sites), whereas heavy metals contaminants dominate in Austria (~60% of land sites) and Macedonia (~89% of land sites).

The relative importance of different contaminant species reported in the 2011 survey is similar to that reported in 2006, with the exception of sites associated with chlorinated hydrocarbons in groundwater, which reported a decrease.

[24] https://www.gov.uk/government/publications/land-remediation-bringing-brownfield-sites-back-to-use/land-remediation-bringing-brownfield-sites-back-to-use (Accessed October 2016).

[25] National Report on the State of Environment in 2011. Ministry of Environment and Forests National Environmental Protection Agency (ROMANIA)

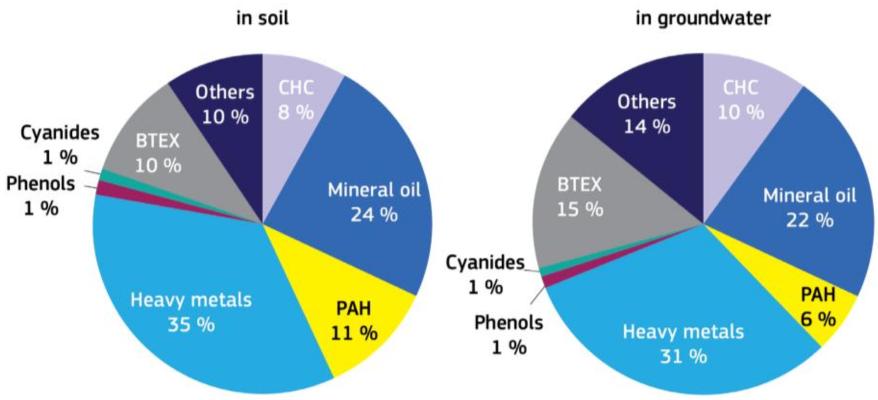


Figure 40. Frequency of contaminant species at EU contaminated sites. Adapted from JRC Progress in management of contaminated sites Report EUR 26376 EN (2014).

6.6 Breakdown of polluting activities to local soil contamination

Legal regulations for the protection of soils have not been agreed at the EU level and only exist in some of the Member States. However, the Integrated Pollution and Prevention Control Directive (IPPC 2008/1/ EC) requires that operations falling under its scope do not create new soil contamination, the Directive on Industrial Emissions (IED 2010/75/ EU) provides a regulatory framework to prevent emissions to soil from large industrial plants, and more indirectly, the Water Framework Directive (WFD 2000/60/EC), the Waste Framework Directive (2008/98/EC) and Landfill Directive (99/31/EC) all provide subsidiary legislative controls on soil contamination and requirements for its management.

Notwithstanding these and similar legislative controls at Member State level (and in some cases regional level), significant new site contamination still occurs as a result of accidents and illegal activities, and a very large number of sites with historical contamination pre-exist. Figure 41 shows the breakdown of polluting activity responsible for the local soil contamination within EU member states. Clearly the polluting activities are specific to individual countries and there is no dominant commercial sector at EU scale.

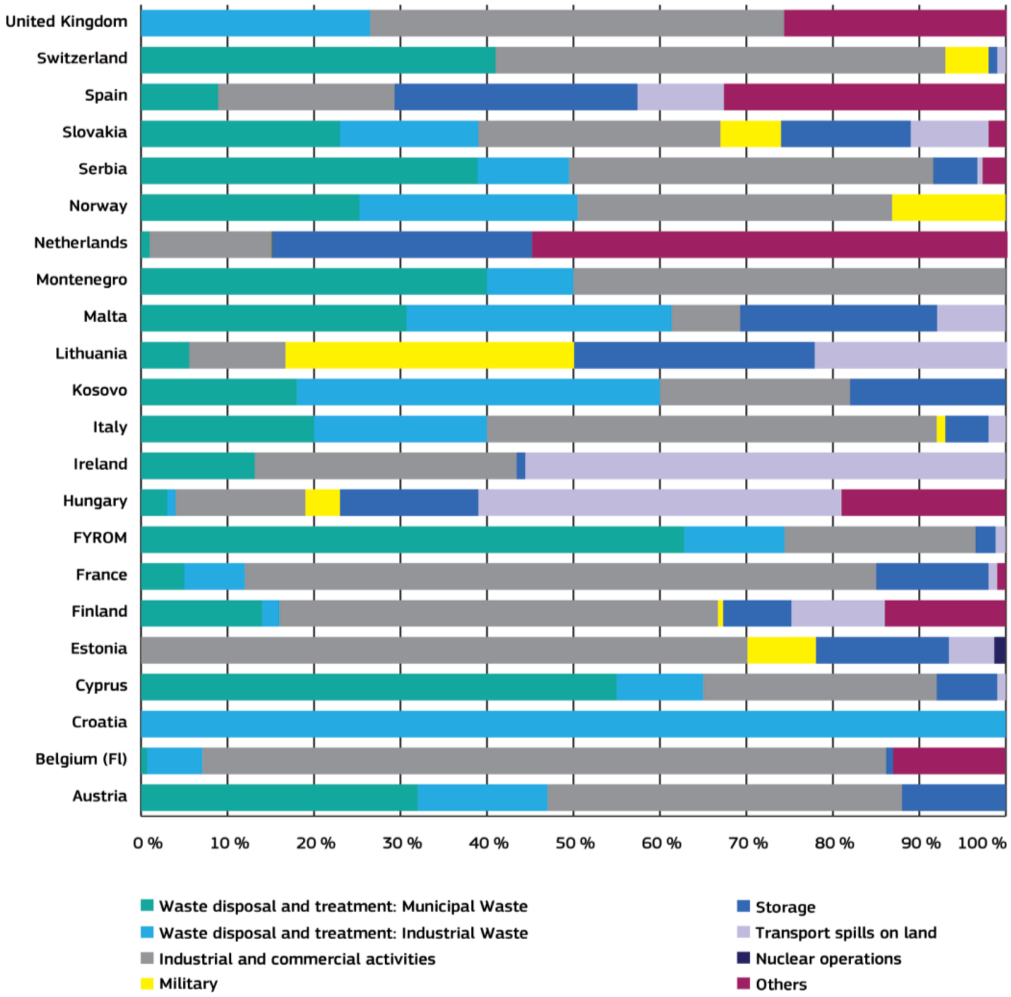


Figure 41. Breakdown of polluting activity responsible for the local land and soil contamination within EU member states. Adapted from JRC Progress in management of contaminated sites Report EUR 26376 EN (2014).

6.7 EU28 Country level inventories for contaminated land

Inventories of polluting activities, potentially contaminated sites and identified contaminated sites are indispensable for monitoring local soil contamination. However, the focus of the EIONET surveys has been with monitoring the management of these sites, collecting information on the existence and nature of centralized data inventories and mapping activities. It has not been the purpose of EIONET to collate information into an EU database, but rather collate information as a guide to data availability. The distribution of EU member states that maintain inventories for contaminated land (JRC 2014) is shown in Figure 42.

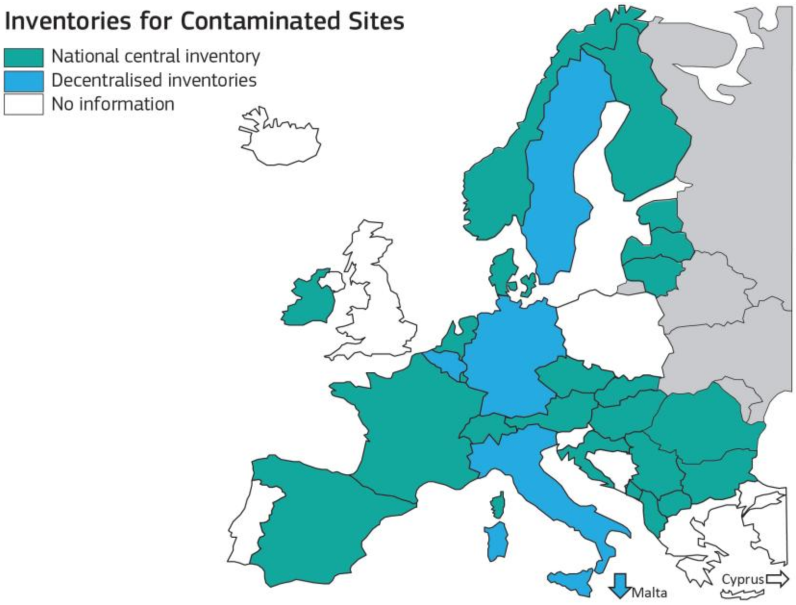


Figure 42. Map showing distribution of EU member states that maintain inventories for contaminated land. Adapted from JRC Progress in management of contaminated sites Report EUR 26376 EN (2014).

EIONET report that 28 of the 39 countries keep comprehensive inventories which largely include polluting activities, potentially contaminated sites and contaminated sites[26]. Of these, 25 countries have centralized national data inventories, 4 countries (Sweden, Belgium, Germany, Italy) rely on regional data inventories, whilst 3 countries (Switzerland, Lithuania, Hungary) have national inventories in addition to regional inventories.

Data held at the European Environment Agency is reliant upon information gained through their partnership network EIONET (European Environment Information and Observation Network) and so is similar in its scope. Information relating to specific problematic contaminated sites, as well as survey data on the progress in management of contaminated sites are available through EIONET or the EEA website[27]. However, the focus of these data is on the number of potential or identified contaminated sites, and whilst this does allow an indicative comparison between the EU countries in terms of the intensity of contamination, it does not provide a scale metric that can be used for the determination of contaminated land area.

In attempting to estimate the area of contaminated land in the EU, it is useful to make cautious comparison with a number of successful brownfield studies (CABERNET 2006, NICOLE 2011) since information in this domain is more developed. Whilst mindful that brownfield sites are not necessarily contaminated areas (risks are more likely perceived than factual in most member states), Table 9 shows data for the estimated area of EU brownfield land that was collated by CABERNET in 2005.

[26] Exceptions: • Cyprus does not include contaminated sites; Macedonia only includes polluting activities; Spain does not include potentially contaminated sites; Greece is in the process of establishing a regional level inventory.

[27] http://www.eea.europa.eu/data-and-maps/data/soil-contamination-1#tab-european-data (Accessed October 2016).

Table 9. Estimated total area of European brownfield land for selected member states. Data is from the CABERNET Network and based on original work by Oliver et al 2005.

Country	Estimated total area of brownfield land
Austria	yes
Belgium	9,000 hectares (Wallonia) 5,500 hectares (Flanders)
Bulgaria	No data available
Czech Republic	30,000 hectares
Denmark	No data
Finland	No data
France	20,000 hectares 5000 hectares (Lorraine) 1000 hectares (Ile de France) 400 hectares (West Rhône Alpes)
Germany	128,000 hectares 18,000 hectares (Saxony)
Greece	No data
Hungary	No data
Ireland	No data
Italy	No national data 1260 hectares (Milan Province)
Latvia	No national data 1900 hectares (Riga only)
Netherlands	9,000 – 11,000 hectares
Poland	800,000 hectares
Portugal	No data
Romania	900 000 hectares
Slovak Republic	No data
Slovenia	Data soon to be available
Spain	No national data Basque Country: 7930 hectares potentially contaminated land, 482 hectares industrial ruins
Sweden	> 5000 hectares (estimate)
United Kingdom	65,760 hectares (England) – full regional data available9 10,847 hectares (Scotland) No data for Wales or Northern Ireland

Evidently there are wide variation in the data: Brownfield land density as a % of total land area are generally between 0.25% - 0.5%, although Sweden and France have particularly low densities of <0.05%, whilst Poland and Romania particularly high densities of 2.5% and 3.8% respectively. Furthermore when the reported number of brownfield sites is considered the discrepancies are further heightened: Data from the French Environment indicate that there are 222,000 brownfield sites covering 20,000 ha, an average of 0.09 ha/site, whilst by contrast, the equivalent Polish average area is 248 ha/site. Discrepancies of this order cannot be explained by differences in the industrial past of these countries and are undoubtedly affected by differences in definitions at the national level discussed previously. Nevertheless, these estimates of the total area of brownfield land can be cautiously indicative of the total contaminated land areas when interpreted through their respective national definitions.

These data can be compared with similar but less ratified data from various sources that attempt to estimate the extent of contaminated land within the EU member states (see Table 10).

Table 10. The extent of contaminated land area in the EU member states.

EU member state	Estimated area of contaminated land (ha)	Note on context	Year	Source reference
Austria	40,000	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Belgium	1,700	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Bulgaria				
Croatia				
Republic of Cyprus	340	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Czech Republic	> 2,982,858.2	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Denmark				
Estonia				
Finland				
France				
Germany	350,000	military areas	2013	Land Quality Management Ltd. SP1004 International Processes for Identification and Remediation of Contaminated Land. Report No.: 1023-0. (2013).
Greece				
Hungary	230	?	2011	EIONET Progress in management of contaminated sites (CSI 015)
Ireland				
Italy				
Latvia	11,568	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Lithuania				
Luxembourg	4,281	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Malta	1,000	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Netherlands				
Poland	800,000	moderately or heavily degraded	2013	Land Quality Management Ltd. SP1004 International Processes for Identification and Remediation of Contaminated Land. Report No.: 1023-0. (2013).
	12000 - 14000	industrial or waste sites	2013	Land Quality Management Ltd. SP1004 International Processes for Identification and Remediation of Contaminated Land. Report No.: 1023-0. (2013).
Portugal				
Romania	410,121	various identified industrial source	2011	National Report on the State of Environment in 2011. MINISTRY OF ENVIRONMENT AND FORESTS NATIONAL ENVIRONMENTAL PROTECTION AGENCY (ROMANIA) p117
	900,000	Est. total	2011	National Report on the State of Environment in 2011. MINISTRY OF ENVIRONMENT AND FORESTS NATIONAL ENVIRONMENTAL PROTECTION AGENCY (ROMANIA) p110
	75,000	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
Slovakia	15,000	?	2011	EIONET Progress in management of contaminated sites (CSI 015)
Slovenia				
Spain	7,898 (Basque only)	of which 3,100 heavily contaminated	2013	Land Quality Management Ltd. SP1004 International Processes for Identification and Remediation of Contaminated Land. Report No.: 1023-0. (2013).
Sweden	300,000	Est. total	2009	Biofuel and other biomass based products from contaminated sites – Potentials and barriers from Swedish perspectives. STATENS GEOTEKNISKA INSTITUT. SWEDISH GEOTECHNICAL INSTITUTE
	12,000	?	2006	EIONET Progress in management of contaminated sites (CSI 015)
UK	400,000	Est. total	2015	Land remediation: Bringing brownfield sites back to use. Department for Internation Trade. HM Government UK.
	300,000	Est. total	2005	Dealing with contaminated land in England and Wales. A review of progress from 2000-2007 with Part 2A of the Environmental Protection Act. UK Environment Agency. Reporting the Evidence.
	300,000	Est. total	2016	Charted Institute of Environmental Health (UK) http://www.cieh.org/policy/contaminated_land.html

Whilst robust estimates for the area of contaminated land within the EU are unavailable, based on the limited data available it is likely that the area of contaminated land within the EU is significant and in the order of 5 Mha to 10 Mha. To expect anything less after 200 years legacy of intense industrialization and limited environmental legislation would seem unrealistic.

6.8 ITAKA trials of camelina on contaminated land sites: case studies

As part of the ITAKA project, camelina cultivation trials have been conducted using indoor controlled experiments with soils spiked with heavy metal contaminants, as well as at pilot scale field trials in heavily contaminated land at locations near Copsa Mica, Rovinari, and Campina in Romania. Full details of these programs are given in ITAKA deliverable D5.7, and are summarized here:

- In the Copsa Mica-Axente Sever village, Sibiu county: heavy metals resulting from a large non-ferrous metal smelting plant have polluted the atmosphere and the soil (diffuse contamination). The test site is located 1 km from the industrial operations. The crop prior to camelina plantation was maize. No fertilizer was applied during the trials.
- In Rovinary-Targu-Jiu, Gorj county: camelina trials were carried out in 2 plots at this location. The main pollution source for the sterile-dump site came from a lignite (coal) overburden, whilst the source for the ash-dump site came from power station fly-ash, and both sites were subject to acid rain from regional SO_2 emissions. The trial sites are located ~2 km from the Garla lignite extraction site. At the sterile-dump site, the crop prior to camelina was maize, while at the ash-dump site the crop prior to camelina was grass. Camelina trials were carried out in both sites. No fertilizer was applied during the trials.
- In Campina, Prahova county: previously pyrite was deposited on the land though has subsequently been removed, and much of the site is covered by debris from building demolition (brownfield site). The nearby lake is polluted with oil and the land was not being cultivated prior to the introduction of camelina. No fertilizer was applied during the trials.

The controlled cultivation trials indicate that camelina has a good degree of tolerance to the presence of the six metals trialled (cadmium, cobalt, copper, iron, vanadium and zinc) in all but the highest concentrations. The trace metals Cd and Co show the greatest potential for uptake into the seed with measured concentrations reaching several hundred times greater than their corresponding natural baseline levels. The data indicate that Cd concentrations in the seed can potentially reach levels that could potentially render the crushed seeds unfit for animal feed.

For the four contaminated field study sites at, Câmpina, Copşa Mică, and Rovinari, a qualitative assessment of the growing crop was used to evaluate crop vigour and vitality, and a post-harvest assessment following the pathway of contaminant heavy metals throughout the agronomy chain from soil, plant matter, harvested seeds, and raw oil was considered.

These preliminary trials show that camelina cultivation in heavily contaminated land is possible, though in many instances the plants show clear signs of stress.

The geochemical characterization of the soil at the four Romanian field sites highlighted the presence of high levels of As, Cd, Cu, Ni, Pb and Zn, whilst elemental analysis of the four plant components of roots, shoots, husks (silicles), and seed found that As, Cu, Fe and Zn could be present at high concentrations within the seed; Shoot to root concentration suggest that camelina has the potential to act as accumulator for Zn and Cd; And analysis of the extracted camelina oil indicated that Cu and Fe were the principal metals present. Hence within the seed there appears to be partitioning between plant material and plant oil.

This study developed an effective methodology for the measurement of metals in the camelina value chain, and evaluated some of the specific vulnerabilities of camelina physiology. It demonstrated that camelina could be grown on contaminated land, although recommends care when considering co-products usage (straw, husks and crushed seed). And whilst limiting co-product usage also limits co-product value, this potential loss must be balanced against the potential expenditure of land remediation, which is typically between 100,000 – 500,000 euros per hectare.

6.9 Summary

Given societies high dependence upon soil for the production of food and eco-services, it is perhaps surprising that at the European level, legislative policy for the protection of soil is uniquely missing (cf. Water Framework Directive 2000/60/EC or Air Quality Directive 2008/50/EC). A draft EU framework directive[28] on the protection of soil that would bring continuity to the definition of contaminated land was proposed in 2007. However after several years of discussion with little progress, the European Commission withdrew the proposal in May 2014. Although when withdrawing the proposal, the European Commission reaffirmed its commitment to the objective of protecting soil and will examine other options on how to achieve this.

It is apparent that land contamination is a widespread infrastructure problem of varying intensity, significance and risk, which affects the whole of the EU. However, addressing the problem of contaminated land is a comparatively recent concern and so detailed inventories and site mapping are not commonly available. Estimates of contaminated land are often dependent upon expert judgement and so are inherently uncertain, and EU scale information is further fragmented due to a lack of common definition between member states.

Because of the variable definitions for contaminated land and the variability in data collection methodologies, indicative data from individual member states is difficult to evaluate, and data from different EU member states is not readily comparable. Inventories for contaminated land are at a nascent stage of development within many EU member states or autonomous regions with aspirational targets that stretch many years into the future (see Annex C), and many initiatives (such as CABERNET[29], NICOLE[30], and COMMON FORUM[31]) highlight the need for a common vision at the regulation level.

Robust and ratified estimates for the area of contaminated land within the EU are unavailable. Information is fragmented and disordered. However, based on the limited data available it is likely that the area of contaminated land within the EU is significant and in the order 5 to 10 Mha. To expect anything less after a 200 years legacy of intense industrialization and limited environmental legislation would seem unrealistic.

[28] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52002DC0179 (Accessed October 2016).

[29] http://www.eugris.info/displayproject.asp?Projectid=4415 (Accessed October 2016).

[30] http://www.nicole.org/ (Accessed October 2016).

[31] http://www.commonforum.eu/ (Accessed October 2016).

7 Estimate of achievable camelina production potential in Europe

Camelina is a crop that can be grown throughout Europe and requires few inputs. However, the scope of this assessment will be limited to camelina grown on low iLUC land.

In this task, an assessment of the achievable camelina production within Europe is being developed by combining current estimates of land availability, with estimates of barley productivity as a surrogate indicator for camelina production. Barley has been chosen as a suitable proxy based on previous experience with camelina production in Spain and similarities in the required agronomic conditions, although appropriate weighting factors are also incorporated.

Within these order of magnitude approximations no consideration of land category, soil category or climatic conditions are being made directly: it is assumed that these parameters are inherently or indirectly taken into consideration by referencing to the productivity of barley within the same region.

[NOTE. This model and the estimate of production volumes have been developed through close collaboration involving SENASA, CCE and MMU].

7.1 Tier 1: EU Country level assessment. A first order estimate of EU28 camelina potential and achievable biojet production (2017-2025)

The Tier 1 assessment of European camelina production potential is a first order calculation that attempts to estimate the bounds of achievable production in the EU using relatively course country level (or NUTS-0) data. The Tier 1 model establishes an upper bound for the camelina production potential and incorporates primary data on the availability of fallow land and barley production yields. Both of these dataset are derived from data compiled by EUROSTAT. Further details on the distribution of fallow land in the EU, as well as barley productivity in the EU are given in the annex section.

Primary assumptions:

1. Camelina is considered to be an acceptable rotational crop in all EU countries.
2. Barley is a suitable surrogate crop to assess the wider potential of camelina in Europe.
3. The experiences of camelina cultivation in Spain and Romania can be (cautiously) extrapolated to other EU regions.

7.1.1.1 Primary data categories:

1. **Average area of fallow land per EU country** (abandoned and polluted is out of scope in this first approach).
2. **Rotation Index**. This variable refers to the proportion of fallow that may be replaced by camelina. A preliminary estimation from CCE assumes the rotation index to be 50% for Productivity Rates (PR) below 2 tonnes/ha, 75% for PR in the range 2-3 tonnes/ha and 100% for PR> 3 tonnes/ha, where PR is referenced to Barley as a suitable proxy based on previous experience with camelina production.
3. **Average yield of (rain-fed) barley per EU country**. Barley productivity has been selected as a baseline surrogate crop for camelina yield calculations.

7.1.1.2 Methodology:

The implementation of the methodology described below by the following step sequence:

- The total area of fallow land for each EU country across with potential for camelina cultivation are order ranked.
- An effective fallow factor to accounts for the fact that not all fallow can be replaced by camelina is applied [for upper limit calculation this factor = 1].
- The rotation index factor, as defined above, is applied to determine the area of potentially addressable fallow land.
- The average barley productivity for each country is used as a proxy to extrapolate the potential of camelina. However, countries where barley productivity is >5 tonne/ha are excluded from the estimation since the economics of camelina become less competitive compared to other oil seed crops in these circumstances.
- For the purpose of this calculation, the approximate “camelina-to-barley” productivity ratio is assumed to be a flat average of 50%, corresponding to medium rainfall pattern (from CCE's estimated range of 40%-60% depending upon rainfall). Hence, camelina productivity is assumed to be half that of barley, so that the maximum camelina grain production on the addressable fallow land can be determined.
- To calculate the corresponding maximum camelina oil production, an average oil extraction factor must be applied. For the purposes of this calculation, a conservative oil extraction factor of 35% has been applied (Typical extraction is 33%-38%, with 2% residual oil remaining in the camelina cake).
- A suitable penetration factor that considers the critical variables affecting the introduction of camelina as a biofuel feedstock and achievable in the 2017 - 2025 timeframe has been defined at country level. This penetration factor has been estimated at the lower end of CCE's expectations (20% - 40% for Spain and Romania and 0% for countries with barley productivity greater than 5 Mt/ha. All other countries use SENASA's conservative estimations.
- The mathematical product of the maximum camelina oil productivity with the estimated penetration factor therefore gives the foreseeable camelina oil production per country, and subsequently the foreseeable camelina biojet production per country using the oil to biojet production ratio of 0.65.

7.1.1.3 Outcomes:

Camelina biojet. The first order estimate shows a camelina HEFA biojet production potential within the EU to be in the region of 234,000 tonnes/year. This estimate would be achievable within the defined timeframe of 2017 – 2025, and is based upon realisable but conservative estimates of market penetration. For details of the market penetration model the reader is referred to deliverable D6.8.

Details of the Tier 1 calculation are shown in Table 12.

The above assessment is specific to HEFA biojet produced using NESTE’s current platform. Improvements in technology could increment this total, and of particular note is the possible (if not probable) ASTM certification of the HEFA+ pathway. The first order estimate for the camelina HEFA+ pathway (sometimes referred to as green diesel) using NESTE’s current technology platform shows the EU biojet production potential be in the region of 284,000 tonnes/year.

Co-products. In addition to the production of camelina oil for biojet, a number of co-products are produced. Some of these co-products are considered to be of economic value and are extracted from the field, whilst others considered to be of low economic value remain on the land as agricultural residues. These low value agricultural residues are nevertheless worth auditing because they have a high environmental value as soil conditioners, increasing soil organic carbon, and sequestering carbon. A good estimate of co-product volumes can be calculated with reference to camelina seed productivity. Table 11 shows an inventory of estimated camelina co-product volumes from the Tier 1 EU camelina production potential for both on field production, and those extracted from the field. Standard multipliers referenced to camelina seed productivity are shown in parenthesis. These estimates would be achievable within the defined timeframe of 2017 – 2025, and are based upon realisable but conservative estimates of market penetration.

Table 11. Inventory of estimated camelina co-product volumes from the Tier 1 EU camelina production potential (2017-2025). Standard multipliers referenced to camelina seed productivity are shown in parenthesis.

Product	Produced on field (tonnes/year)	Extracted from field (tonnes/year)
Seed	1,028,000 (100% of seed wt.)	1,028,000 (100% of seed wt.)
Husks	2,056,000 (200% of seed wt.)	257,000 (25% of seed wt.)
Straw	5,142,000 (500% of seed wt.)	0 (0% of seed wt.)
Oil	360,000 (35% of seed wt.)	360,000 (35% of seed wt.)
Meal	658,000 (64% of seed wt.)	658,000 (64% of seed wt.)

Table 12. Tier 1 calculation: First order estimate of EU camelina biojet production potential (2017-2025).

Country	Fallow Area ('000 Ha)	Effective fallow factor	Rotation Index	Addressable Fallow Area ('000 Ha)	Barley Productivity (t/Ha)	Maximum Barley Production (t)	Maximum Camelina Grain Production (t)	Maximum Camelina Oil Production (t)	Guesstimated Penetration 2025	Foreseable Camelina Oil Production 2025 (tonnes)	Foreseable Camelina Biojet Production 2025 (tonnes)
Spain	3,156	1	75%	2,367	2.87	6,792,377	3,396,189	1,188,666	20%	237,733	154,527
Romania	580	1	75%	435	2.89	1,256,188	628,094	219,833	20%	43,967	28,578
Italy	494	1	100%	494	3.66	1,808,772	904,386	316,535	10%	31,654	20,575
France	488	1	100%	488	6.16	3,008,988	1,504,494	526,573	0%	0	0
Poland	447	1	100%	447	3.53	1,576,145	788,073	275,825	10%	27,583	17,929
Portugal	333	1	50%	167	1.18	196,512	98,256	34,390	10%	3,439	2,235
Finland	254	1	100%	254	3.43	871,220	435,610	152,464	0%	0	0
Germany	199	1	100%	199	6.38	1,268,982	634,491	222,072	0%	0	0
Sweden	158	1	100%	158	4.54	715,050	357,525	125,134	0%	0	0
United Kingdom	156	1	100%	156	5.87	915,720	457,860	160,251	0%	0	0
Greece	151	1	75%	114	2.93	332,658	166,329	58,215	10%	5,822	3,784
Hungary	145	1	100%	145	3.85	558,835	279,418	97,796	10%	9,780	6,357
Bulgaria	121	1	100%	121	3.73	452,408	226,204	79,171	0%	0	0
Lithuania	91	1	100%	91	3.18	290,334	145,167	50,808	0%	0	0
Latvia	62	1	100%	62	2.63	162,271	81,136	28,397	0%	0	0
Estonia	41	1	100%	41	2.98	122,180	61,090	21,382	0%	0	0
Austria	39	1	100%	39	5.11	197,118	98,559	34,496	0%	0	0
Slovakia	25	1	100%	25	3.70	90,664	45,332	15,866	0%	0	0
Czech Republic	24	1	100%	24	4.71	112,004	56,002	19,601	0%	0	0
Cyprus	12	1	50%	6	1.53	8,862	4,431	1,551	0%	0	0
Belgium	8	1	100%	8	8.42	71,233	35,617	12,466	0%	0	0
Netherlands	8	1	100%	8	6.79	55,678	27,839	9,744	0%	0	0
Denmark	6	1	100%	6	5.56	35,150	17,575	6,151	0%	0	0
Malta	5	1	50%	3	0.00	0	0	0	0%	0	0
Croatia	5	1	100%	5	3.96	19,360	9,680	3,388	0%	0	0
Ireland	2	1	50%	1	7.32	6,090	3,045	1,066	0%	0	0
Luxembourg	0	1	50%	0	5.28	1,183	591	207	0%	0	0
Slovenia	0	1	50%	0	4.48	1,004	502	176	0%	0	0
TOTAL	7,010		*87%*	5,862	*4.17*	20,926,986	10,463,493	3,662,223	*3%*	359,976	233,984

Barley to Camelina productivity Ratio	50%
Oil extraction efficency	35%
Camelina oil to biojet production ratio	65%

7.2 Tier 2: NUTS-2 level assessment. A second order estimate of EU28 camelina potential and achievable biojet production (2017-2025)

To derive a second order estimate of the camelina cultivation and biojet production potential in the EU, regionally averaged statistical data at NUTS-2 resolution sourced from Eurostat for barley productivity, aridity data sourced from GCIAR, semi-empirical data for the barley to camelina production ratio, and CORINE land cover data from the European Environment agency have been used. A brief overview of these additional parameters is given below.

7.2.1 Barley to camelina ratio

Experimental field data collected by CCE has shown that barley productivity can be used as an appropriate surrogate crop for predicting the production yields of camelina. Experimental data from 7 R&D camelina plots and data from farmers corresponding to the three campaigns already harvested are shown in Figure 43.

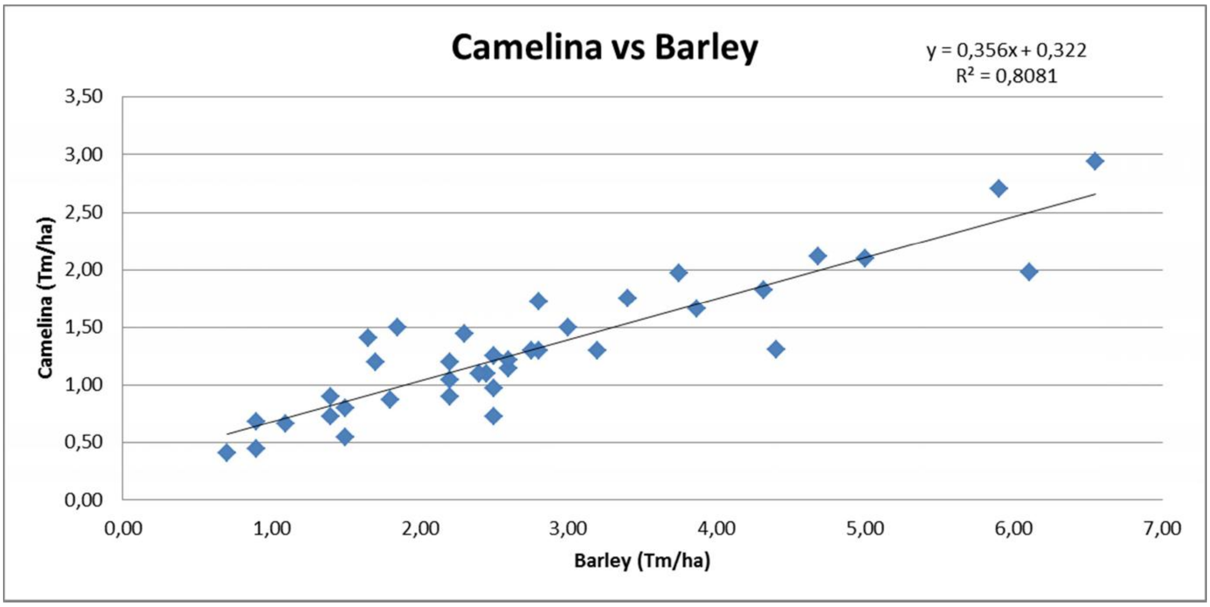


Figure 43. Experimental field data collated by CCE for the relation between camelina and barley productivity yields.

Barley (t/ha)	0,75	1	1,	2	2,	3	3,	4	4,	5
Camelina (t/ha)	0,59	0,68	0,86	1,03	1,21	1,39	1,57	1,75	1,92	2,10
Ratio	79%	68%	57%	52%	48%	46%	45%	44%	43%	42%

The experimental data show that there is an almost linear relation between the productivity yields of barley with the productivity yields of camelina. This relation may be expressed as:

Camelina yield (Tonnes/ha) = 0.356 * Barley yield (Tonnes/ha) + 0.322 (1)

Note that the above data are from CCEs experience of camelina cultivation in Spain and Romania, and hence this relation may not be valid in all EU bioclimatic regions. Nevertheless, the above relation will be extrapolated to the whole of the EU28 region with the understanding that the associated uncertainties may be significant.

7.2.2 Aridity index for EU28

The aridity index (AI) is defined as the ratio of the mean annual precipitation (P) to the mean annual potential evapotranspiration (PET).

$$AI = P / PET \tag{2}$$

where both P and PET must be expressed in the same units, e.g., in millimetres. Potential evapotranspiration is the amount of water that would be evaporated and transpired if there were sufficient water available, and it is conventionally calculated at climate stations on a short grass reference surface. It is however, a difficult parameter to determine over a larger scale.

Because of the complexity in estimating PET, often from a limited meteorological parameterization, a number of methodologies have been developed. Amongst the equations formulated to estimate PET, the FAO application of the Penman-Monteith equation (FAO-PM) is widely considered as a standard method. This is a predominately physically based approach, which can be used globally because it does not require estimations of site-specific parameters. However, the major drawback of the FAO-PM method is its need for specific data for a variety of parameters (i.e. windspeed, relative humidity, solar radiation, etc.) These parameters are especially lacking in developing countries.

A comparison between five different methods of calculating PET to verify suitability for the development of the CGIAR analysis is given within the CGIAR documentation (available at www.cgiar-csi.org). The methodologies tested were: Thornthwaite (Thornthwaite, 1948), Thornthwaite modified by Holland (Holland and Veizer, 1979), Hargreaves (Hargreaves et al., 1985), Hargreaves modified by Droogers (Droogers and Allen, 2002), and the FAO Global Penman-Monteith Dataset (Allen et al., 1998), and results are given as the mean difference between observed and predicted estimates. The results of this and other comparative studies within the literature show that the Thornthwaite and Hargreaves PET methodologies differ by a factor of between 1.3 and 1.5, the correlation being location specific.

These differences are important since bioclimatic zones are defined from the value of the aridity index, typically: Arid ($0 < AI < 0.2$); Semi-arid ($0.2 < AI < 0.5$); Sub-humid ($0,5 < AI < 0.75$); and Humid ($AI > 0.75$). Hence differences in quantitative values and a lack of continuity in PET estimation methodologies could introduce sizeable uncertainties into the EU camelina exploitation model. For example, the aridity data that is used throughout Spanish agriculture and endorsed by MAGRAMA uses the Thornthwaite methodology to estimate PET, whereas the CGIAR aridity data uses the Hargreaves methodology to estimate PET for Europe, and the CGIAR data infer that Spain to be notably more arid than MAGRAMA data. (the parameterization of the Thornthwaite and Hargreaves PET methodologies in shown in Annex D).

This is pertinent to the present discussion as the Tier 2 model draws from, and is reference to, a predominantly Spanish experience with camelina. Nevertheless, for the extrapolation of the exploitation plan to other parts of the EU it is important that we use a consistent approach. The CGIAR is consistently applied across the EU and hence so will be used here for the development of a standard Tier 2 method.

The CGAIR Global-Aridity datasets are provided for non-commercial use in standard ARC/INFO Grid format, at 30 arc seconds (~1 km at equator), to support studies contributing to sustainable development, biodiversity and environmental conservation, poverty alleviation, and adaption to climate change globally, and in particular in developing countries. The methods used to derive these datasets, and the data dictionary, are described discussed further in Trabucco et al. (2008), Zomer et al. (2008) and Zomer et al. (2007). The Global-PET and Global-Aridity are both modelled using the data available from WorldClim Global Climate Data (http://WorldClim.org).

Primary assumptions:

1. Camelina is considered to be an acceptable rotational crop in all EU countries.
2. Barley is a suitable surrogate crop to assess the wider potential of camelina in Europe.
3. Aridity index from CGIAR are representative in all EU regions
4. The experiences of camelina cultivation in Spain and Romania can be (cautiously) extrapolated to other EU regions.

7.2.2.1 Primary data categories:

1. **Low iLUC land availability at NUTS-2 resolution.** The principal categories of low iLUC land in Europe include:
    a. Fallow land. [Fallow land is defined as arable land in a crop rotation that is not harvested during a particular survey year. Data on fallow land at NUTS-2 resolution is available from Eurostat].
    b. Abandoned land. [Abandoned land is difficult to identify. Most authorities do not keep formal records, as there is no requirement to do so].
    c. Polluted land. [Polluted land is similarly difficult to identify. Most authorities do not keep formal records, as there is no requirement to do so. In addition, landowners are often reluctant to accept the categorization due to the implicit responsibility and associated devaluation of the land].

However, within these categories only fallow land will possess the necessary manpower, access to machinery, and infrastructure to permit the development of a viable camelina business opportunities in a near term scenario. Abandoned land within the EU is commonly neglected because it is difficult to access, fragmented or of low productivity, although substantial blocks of arable land can also be abandoned for socio-economic reasons such as that found within EU associated countries such as Ukraine. Polluted land has been identified as a significant and unutilized resource that could potentially be exploited for the cultivation of energy crops. However, the investigation into the cultivation of camelina on contaminated land as part of the ITAKA project has shown that our understanding of this technology is currently insufficient to be of general applicability and land appraisals must be conducted on a site-by-site basis. Hence only fallow land defined as arable land in a crop rotation that is not harvested during the survey year will be considered within this assessment. The broader more expansive exploitation of abandoned and polluted land is unlikely to be realisable in the time frame 2017 – 2025.

2. **Average yield of (rain-fed) barley at NUTS-2 resolution.** Barley productivity in dryland areas has been selected as a baseline surrogate crop for camelina yield calculations.
3. **CORINE land cover.** The CORINE database is an inventory of land cover categorized into 44 classes, and presented as a cartographic product at a scale of 1:100 000. This database is operationally available for most areas of Europe. Data is sourced from the European Environment Agency (EEA).
4. **Aridity index.** The aridity index database is an inventory of land aridity presented as a cartographic product at a resolution of 30 arc seconds. Data is sourced from CGIAR.

5. **Minimum fallow.** This variable has been introduced in recognition of the fact that fallowing can play an important role within crop rotational schemes in certain more arid regions. Not all of the fallow land is available for camelina cultivation. This minimum fallow variable is dependent upon the aridity index at the specific location and has been estimated by CCE based upon wide experience support by some empirical evidence. For arid regions (0 < AI < 0.2) minimum fallow is 50%; Semi-arid regions (0.2 < AI < 0.5) minimum fallow is 28.6%; Sub-humid regions (0,5 < AI < 0.75) minimum fallow is 20%; and Humid (AI > 0.75) minimum fallow is 0%.

7.2.2.2 Methodology:

The implementation of the methodology described below.

- The areas of fallow land across the EU with the potential for camelina cultivation are identified at NUTS-2 spatial resolution. Data is sourced from Eurostat. The Eurostat definition of fallow land necessarily excludes all protected areas and non-certifiable land from this classification.
- The arable land categorization of the CORINE land cover database is used to mask the EU aridity index mapping. The result shows the distribution of aridity in EU arable land.
- The distribution of aridity in EU arable land is then masked into NUTS2 regions. The result shows the distribution of aridity in EU arable land for each NUTS2 region.
- The distribution of aridity in EU arable land for each NUTS2 region calculated above is then subdivided into the standardized aridity classes defined above (Arid (0 < AI < 0.2); Semi-arid (0.2 < AI < 0.5); Sub-humid (0,5 < AI < 0.75); and Humid (AI > 0.75)), and pixel counting is used to calculate the area of land (ha) within each aridity class for each NUTS2 region.
- The percentage of fallow land in each NUTS2 region is calculated from the fraction of fallow land area, to the total arable land area within the CORINE land cover database. In any given NUTS2 region, it is assumed that this percentage fallow is distributed evenly across the aridity index classes.
- The difference between the actual fallow and the minimum fallow gives the percentage of low LUC fallow land that is addressable for the cultivation of camelina, where minimum fallow is predefined for each aridity class.
- The area of low LUC fallow land that is potentially available for camelina cultivation is then calculated from this addressable percentage and the area of land (ha) within each aridity class for each NUTS2 region.
- The average barley productivity for each NUTS2 region is used as a proxy crop to extrapolate the potential of camelina. However, NUTS2 regions where barley productivity is >5 tonne/ha are excluded from the estimation since the economics of camelina become less competitive compared to other oil seed crops in these circumstances.
- For the purpose of the Tier 2 calculation, the approximate "barley-to-camelina" productivity ratio is given by equation 1. Hence the maximum camelina grain production on the addressable low LUC fallow land can be determined.
- To calculate the corresponding maximum camelina oil production, an average oil extraction factor must be applied. A conservative oil extraction factor of 35% has been applied (Typical extraction is 33%-38%, with 2% residual oil remaining in the camelina cake).
- For this Tier 2 estimation, the maximum foreseeable camelina oil production per NUTS2 region, and subsequently the maximum foreseeable camelina biojet production per NUTS-2

region are derived. The provision of suitable penetration factors that consider the critical variables affecting the introduction of camelina within specific NUTS2 regions and that are achievable in the 2017 - 2025 timeframe are beyond the scope of the present study. Further details on the penetration model can be found in ITAKA deliverables D6.4 and D6.8.

7.2.2.3 Outcomes:

Addressable low LUC fallow land. Across all regions of the EU, the total addressable low LUC fallow land estimated to be 3,220,000 ha. If specific NUTS2 regions where barley productivity is > 5 tonnes/ha are excluded from the calculation, then the total addressable low LUC fallow land is reduced to 1,865,000 ha.

Maximum camelina oil and biojet. From the Tier 2 exploitation model with the exclusion of high productivity land (>5 tonnes/ha), it is estimated that the maximum camelina oil production potential within the EU to be approximately 1,104,000 tonnes/year. This corresponds to a maximum camelina biojet production potential using the HEFA pathway of approximately of 717,000 tonnes/year. Improvements in technology could increment this total, and of particular note is the possible (if not probable) ASTM certification of the HEFA+ pathway. The corresponding maximum estimate for the camelina HEFA+ pathway (sometimes referred to as green diesel) using NESTE's current technology platform shows the EU biojet production potential be in the region of 872,000 tonnes/year.

The above estimates differ from those presented in the Tier 1 estimation in that they do not include a penetration factor. Consequently, within the defined timeframe of 2017 – 2025 it is highly uncertain whether these estimates would be achievable. Market penetration factors that integrate expert judgement to assess key assumptions such as the approval and affordability of herbicides and agricultural insurance, as well as CAP incentives, comparative pricing and incremental crop yields are being developed elsewhere in ITAKA. Full details of the Tier 2 exploitation model, penetration factors and calculation can be found in ITAKA deliverables D6.4 and D6.8.

Co-products. In addition to the production of camelina oil for biojet, a number of co-products are produced. Some of these co-products are considered to be of economic value and are extracted from the field, whilst others considered to be of low economic value remain on the land as agricultural residues. These low value agricultural residues are nevertheless worth auditing because they have a high environmental value as soil conditioners, increasing soil organic carbon, and sequestering carbon. A good estimate of co-product volumes can be calculated with reference to camelina seed productivity. Table 13 shows an inventory of maximum camelina co-product volumes estimated from the Tier 2 EU exploitation model for both on field production, and those extracted from the field. Standard multipliers referenced to camelina seed productivity are shown in parenthesis.

Table 13. Inventory of maximum camelina co-product volumes estimated from the Tier 2 EU exploitation model. Standard multipliers referenced to camelina seed productivity are shown in parenthesis.

Product	**Produced on field (tonnes/year)**	**Extracted from field (tonnes/year)**
Seed	3,154,000 (100% of seed wt.)	3,154,000 (100% of seed wt.)
Husks	6,308,000 (200% of seed wt.)	788,000 (25% of seed wt.)
Straw	15,771,000 (500% of seed wt.)	0 (0% of seed wt.)
Oil	1,104,000 (35% of seed wt.)	1,104,000 (35% of seed wt.)
Meal	2,019,000 (64% of seed wt.)	2,019,000 (64% of seed wt.)

Camelina straw represents the greatest quantity of biomass, followed by husks and seed. These residues serve an important environmental function but also represent a considerable reservoir of biomass energy. For example, if just 20% of the 15.7 million tonnes of camelina straw were to be mobilized as biomass for power or heat generation each year, a considerable fraction of the embedded 50 Peta Joules of energy could be utilized[32].

[32] Based on LHV energy content of camelina straw of 16 MJ/kg

8 Conclusions

The ITAKA project has targeted camelina oil as a highly promising sustainable feedstock that can be cultivated within Europe in meaningful quantities and in a timely way that is also scalable. Both biofuel and feedstock sustainability have been assessed against the RSB EU RED Standard.

The low LUC model implemented within ITAKA has thus far targeted fallow land in arid or semi-arid regions of Spain, and to a lesser extent Romania. The model recognises that fallowing serves a valuable agronomic purpose such that not all fallow land is truly available, and has focused on the margin between minimum fallow and actual fallow. The scale up of this approach at EU level requires an assessment of potentially available low iLUC land that might be targeted including fallow, abandoned and contaminated lands. On these lands camelina production can be considered to have no or low risk of LUC since it does not displace prior production.

The importance of strategic land use planning to minimise LUC is highlighted by the many controversies surrounding first generation biofuels, and the identification of low iLUC land is key for the wider acceptance of EU biofuels. The objective of this task has been to evaluate the availability of land compatible with the ITAKA low iLUC model and that is potentially accessible to scale-up EU camelina feedstock production on a near to mid-term horizon.

Key results and conclusions from the assessment of land availability are summarized as follows:

- As a precursor to the identification of potential low LUC land, a broad scale assessment of land suitable that included EU climate, soil characteristics, and specific variables relevant to cultivation camelina was considered. This assessment showed that the majority of Europe is generally suitable for camelina cultivation, although Southern Europe has a preferable climate (dry & frost free) and soils (less peaty & lower water table) than Northern Europe.
- Data for fallow land indicates that the total area across the EU has steadily decreased from 2002 when it was >11.6 Mha, to 2013 when it was >6.5 Mha, with many countries showing a high degree of variability.
- At country level, Spain has the largest area of fallow land with >3 Mha every year between 2002 and 2013. Poland, France and Romania were the only other EU member nations with >1 Mha of fallow land in at least one year between 2002 and 2013.
- At NUTS-2 resolution, the regions with the largest areas of fallow land in 2005, 2007, 2010 and 2013, and by a considerable margin, were all in Spain. Other countries that consistently had NUTS-2 regions with large areas of fallow land across the four years were Portugal, France, Poland and Lithuania.
- Hence there are potentially large areas of fallow land within the EU and particularly within Spain that, subject to minimum fallow criteria, may be available for camelina cultivation. Fallow land is considered a near term opportunity for camelina scale up since it is probable that the necessary manpower, access to machinery, and infrastructure will be available.
- There is strong evidence for widespread abandonment of farmland in Southern and Eastern Europe. This abandonment generally falls into two categories: the collapse of the USSR in the early 1990's impacted Eastern Europe, and the decline of traditional livelihoods and the limited profitability of dryland farming in Southern Europe. However, recent evidence of recultivation on abandoned land in Eastern Europe implies that available land in this region may be rapidly declining, and the potential of any abandoned land must be assessed on a site-specific basis.
- Earth-observation based methods to provide continued monitoring of agriculture have good potential for this area particularly with the increase availability of moderate resolution (<30 m) data from Landsat 8 and Sentinel 2. A preliminary study in Spain has highlight large-

scale abandonment of traditional agriculture and olive groves, but this land is unlikely to be suitable for camelina or other arable crops.

- Using published NUTS2 resolution statistical data to derive a regional and aggregated estimate of abandoned land would suggest that there might be 8.8 Mha of agricultural abandonment in the EU, whilst for the same calculation using similarly aggregated but national (NUTS0) resolution data would suggest this estimate is decrease to 6.8 Mha.
- Abandonment is a complex social, political and economic issue. The presence of large areas of abandoned land should be interpreted with caution; many areas may have environmental, economic or social limitation that may render them unsuitable for biofuel production. Planned development must take into account the site-specific conditions and limitations that may be present.
- It is apparent that land contamination is a widespread infrastructure problem of varying intensity, significance and risk, which affects the whole of the EU. Inventories for contaminated land are at a nascent stage of development within many EU member states or autonomous regions, with aspirational targets for the completion of land audits that stretch many years into the future.
- Current estimates of contaminated land are dependent upon expert judgement and so are inherently uncertain, and EU scale information is further fragmented due to a lack of common definition of land types between member states.
- Robust and ratified estimates for the area of contaminated land within the EU are unavailable. Information is fragmented and disordered. However, based on the limited data available it is likely that the area of contaminated land within the EU is significant and possibly in the order 5 to 10 Mha. To expect anything less after a 200 year legacy of intense industrialization and limited environmental legislation would seem unrealistic.
- For the cultivation of camelina in heavily contaminated soils, attention should be paid to potential re-exposure of humans, animals and wildlife to contaminants through the use of co-products. Limiting co-product usage will limit co-product value, but this potential loss must be balanced against the potential expenditure on land remediation, which is typically 100,000 – 500,000 euros per hectare[33].

The second objective of this task has been to develop models that can be used to assess the production potential of camelina in the EU. These models have been developed in association with CCE and SENASA, and target the defined timeframe of 2017 – 2025. However, within this timeframe, addressable fallow is the only low iLUC land category that land will possess the necessary manpower, access to machinery, and infrastructure to permit the development of viable camelina cultivation opportunities.

Key results and conclusions from the assessment models are summarized as follows:

- Using the first order assessment model and member state (NUTS0) resolution data, it is estimated that the EU camelina oil production potential is approximately 360,000 tonnes/year, which would corresponds to a HEFA biojet production potential of 234,000 tonnes/year. This estimate would be achievable within the defined timeframe, using just available fallow land, and is based upon realisable but conservative estimates of market penetration.
- Using the second order higher fidelity assessment model that is built on NUTS2 resolution data and is similarly limited to just fallow land, but which excludes high productivity land (>5 tonnes/ha), estimates the maximum EU camelina oil production potential to be

[33] For example see http://blog.soilutions.co.uk/2011/08/19/is-this-really-the-cost-of-soil-remediation/

approximately 1,104,000 tonnes/year. This corresponds to a maximum camelina HEFA biojet production potential of approximately of 717,000 tonnes/year. However, the estimates in this model do not include a penetration factor and therefore represents an upper limit. Within the defined timeframe of 2017 – 2025 it is uncertain whether these estimates could be achievable

- Estimates of co-product volumes are also included. Some of co-products are considered to be of economic value and are extracted from the field, whilst others considered of low economic value remain on the land as agricultural residues. These low value agricultural residues are nevertheless worth auditing because they have a high environmental value as soil conditioners. Camelina straw represents the greatest quantity of biomass, followed by husks and then seed. These residues represent a considerable reservoir of biomass. For example, if just 20% of the estimated 15.7 million tonnes/year of camelina straw were to be mobilized as biomass for power or heat generation, a considerable fraction of the embedded 50 Peta Joules of energy could be utilized.
- Camelina cultivation on low LUC abandoned and contaminated land is predicted to be more difficult to implement due to the lack of agronomic infrastructure, and so is envisaged as mid-term realisable opportunities. Modelling the production potential on these land types is obstructed by several unknown parameters such as camelina productivity, barley to camelina productivity, localized aridity, CAP compliance and penetration factors that will be specific to these land types. Simple scaling by reference to surface area excludes the underlying uncertainties.

9 Future research needs

The importance of strategic land use planning and the impact of LUC is highlighted by controversy over EU biofuel developments and meeting future food and energy requirements. The objective of this task was to evaluate the availability of low LUC land compatible with the ITAKA model that is potentially accessible to scale-up camelina feedstock production on a near to mid-term horizon. Through the development of this work a number of specific recommendations as well as inconsistencies, data deficiencies, and research gaps have been identified:

- The definition of contaminated land within member state legislation is widely disparate across the EU. The definition of abandoned land within member state legislation is similarly widely disparate across the EU. These definitions should be unified. An EU framework directive on the protection of soil is greatly needed. Such a framework should include specific wording that would bring continuity to the definition of contaminated land and abandoned land.
- Ratified estimates of contaminated land area at national and EU scale are not available. Information is fragmented and disordered. Whilst it is recognized that this is a difficult parameter to assess and will be dependent upon expert judgement, it is nevertheless an important metric for the estimation of scale. The EIONET network provides an instrument that is well positioned to develop wider data collection using unified methodologies.
- Research initiatives such as CABERNET, NICOLE, and COMMON FORUM play a vital role in the development of sustainable land management and knowledge transfer. They highlight the need for a common vision to address the legacy of our industrial past. Similar programs should be developed.
- It is apparent that the situation regarding land abandonment needs to be monitored and also integrated with research on the potential causes of land abandonment. If land abandonment becomes a significant issue, policy makers need to understand the underlying reasons and be in a position to decide what, if anything, should be done. Land abandonment may have significant socioeconomic and environmental impacts.
- Aggregated statistics are not ideally suited for monitoring agricultural abandonment. As cumulative expansion into new areas will obscure the continued abandonment of previously farmed land. Field/plot level statistics would be desirable.
- New Earth-observation data streams such as Sentinel's 1 and 2 and Landsat 8 offer improved spatial and temporal resolution sufficient for near real time agricultural monitoring. Improved estimates of land abandonment and fallowing should be possible. Studies in the US have managed to map national agriculture at a field level and produced data on crop types (Yan and Roy, 2016) and further development of this area is needed.
- Case studies that examine the socioeconomic impact of contaminated land and subsequent remediation upon local and regional communities are needed. Such studies should be pan-European to capture cultural distinctions.
- The ITAKA pilot scale field trials used to assess the potential of growing camelina on contaminated and brownfield sites should be continued and expanded. Further research to investigate the complexities of plant physiology, the impact of fertilizer, and the partitioning of contaminants within the plant material are needed. Site specific effects and the bioavailability of contaminate species require better understanding.

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Annex A Distribution of fallow land in the EU-28 by NUTS-2 region

In the following Figures, the distribution of fallow land at NUTS-2 resolution is given for individual countries across the EU-28. The total area of fallow land in a particular region is indicated by the associated colour key. Where available, 2013 data are presented. Where 2013 data are not available, 2010 data are presented. Data are sourced from Eurostat.

Figure 44. The distribution of fallow land for Austria, Belgium, Bulgaria and Croatia for the year 2013. Data are sourced from Eurostat.

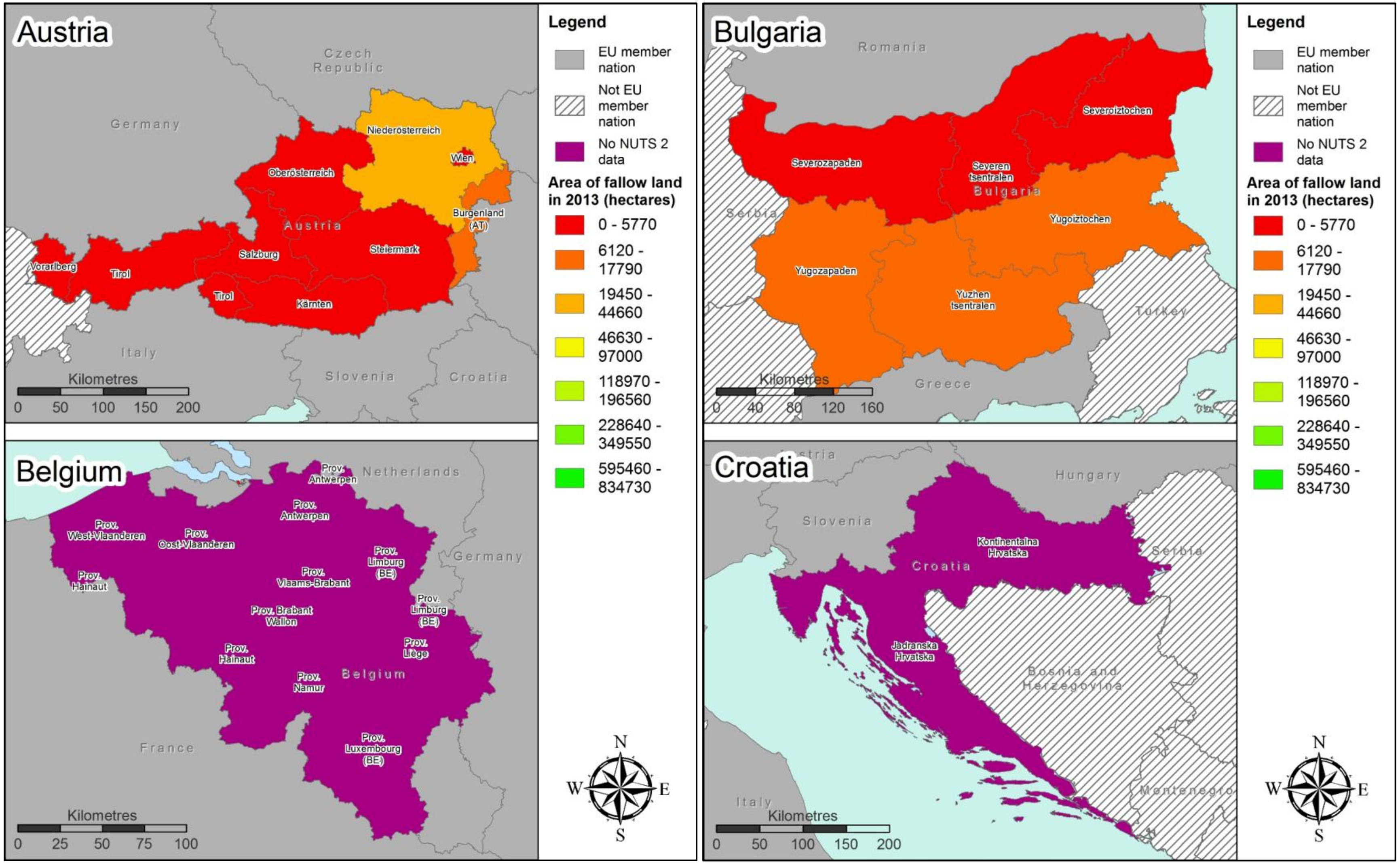


Figure 45. The distribution of fallow land for Cyprus, Czech Republic, Denmark and Estonia for the year 2013. Data are sourced from Eurostat.

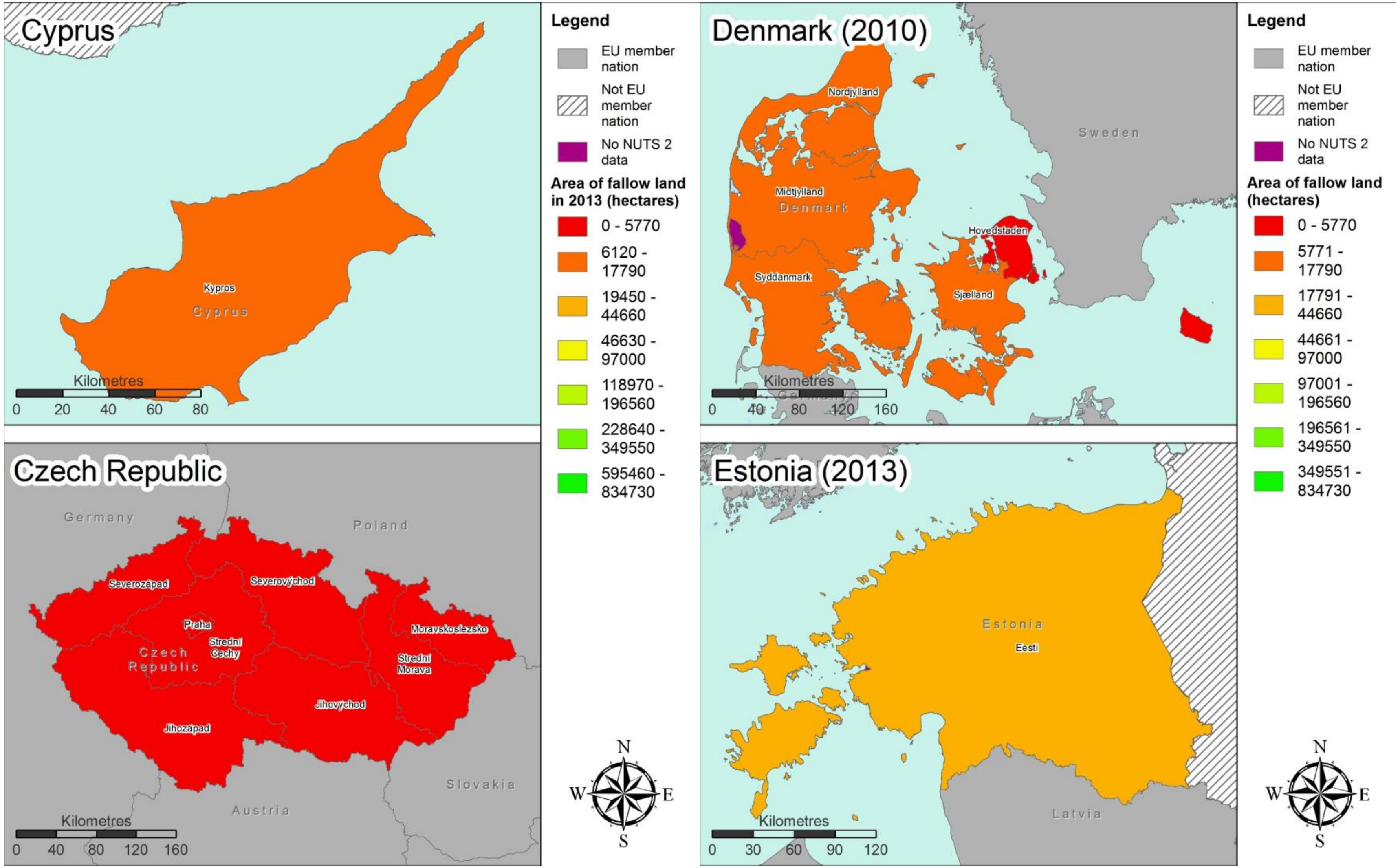


Figure 46. The distribution of fallow land for Finland, France, Greece (at NUTS-1) and Germany for the year 2013. Data are sourced from Eurostat.

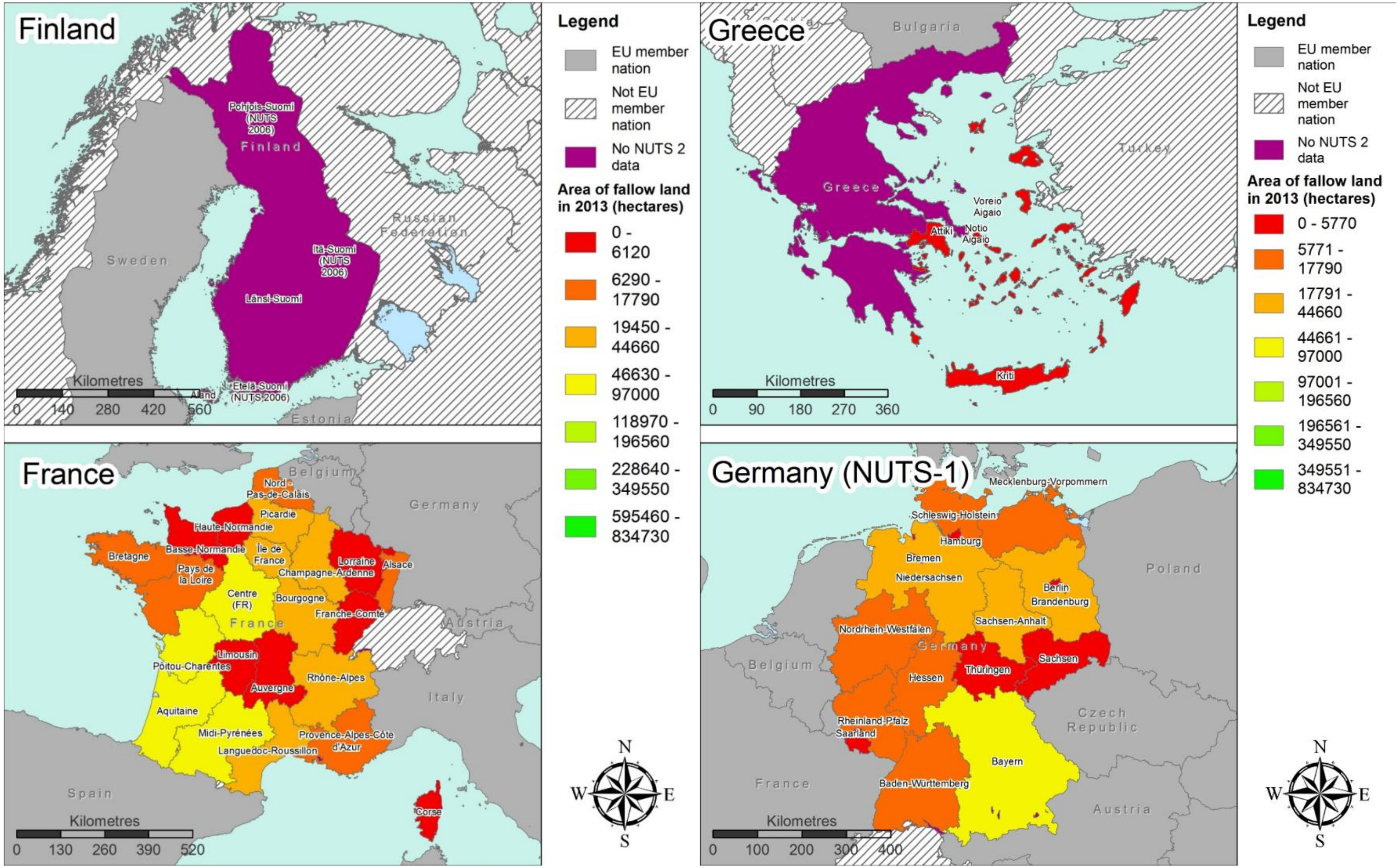


Figure 47. The distribution of fallow land for Hungary and Italy for the year 2010, as well as Ireland and Latvia for the year 2013. Data are sourced from Eurostat.

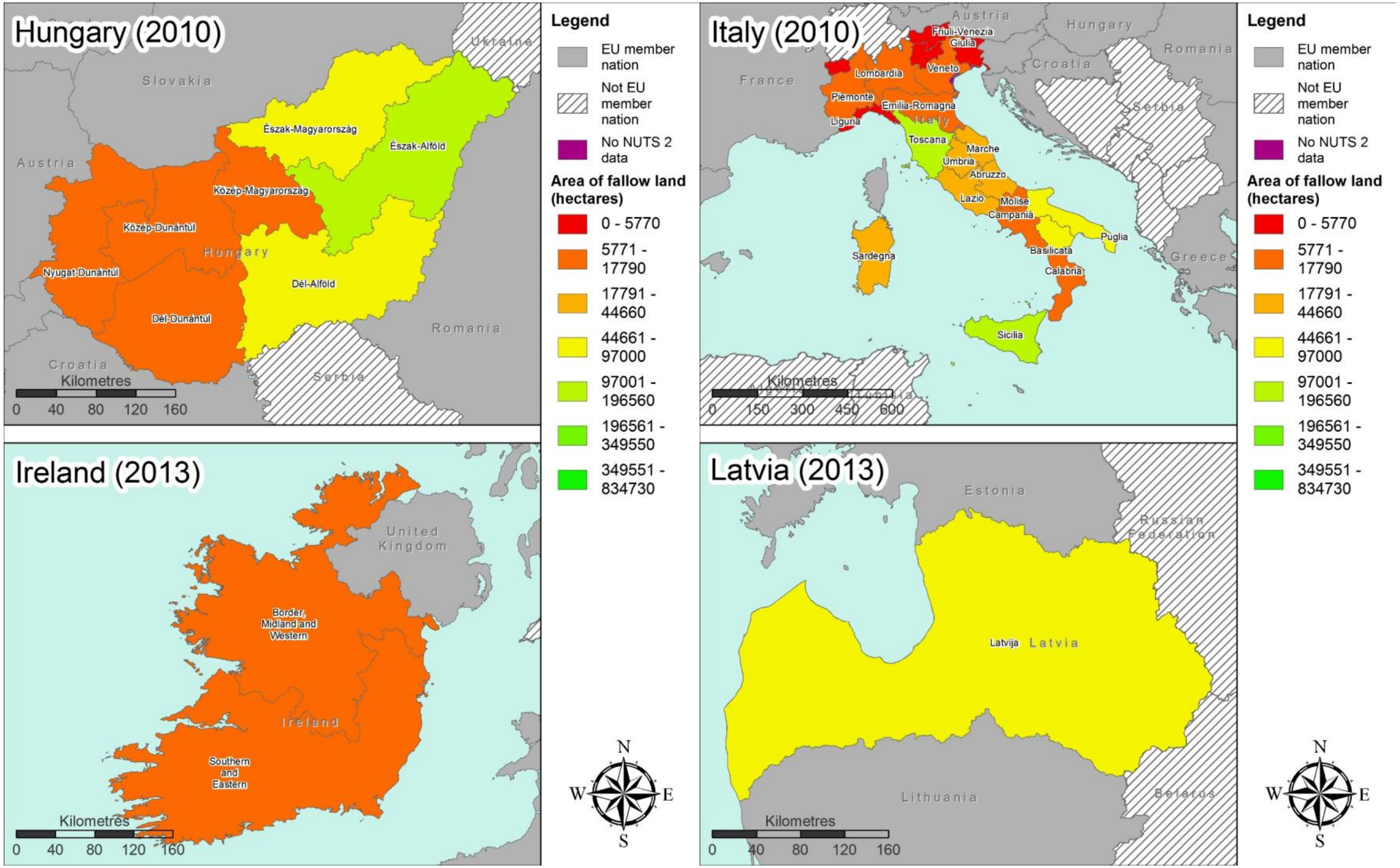


Figure 48. The distribution of fallow land for Lithuania, Luxembourg and the Netherlands for the year 2013 as well as Malta for the year 2010. Data are sourced from Eurostat.

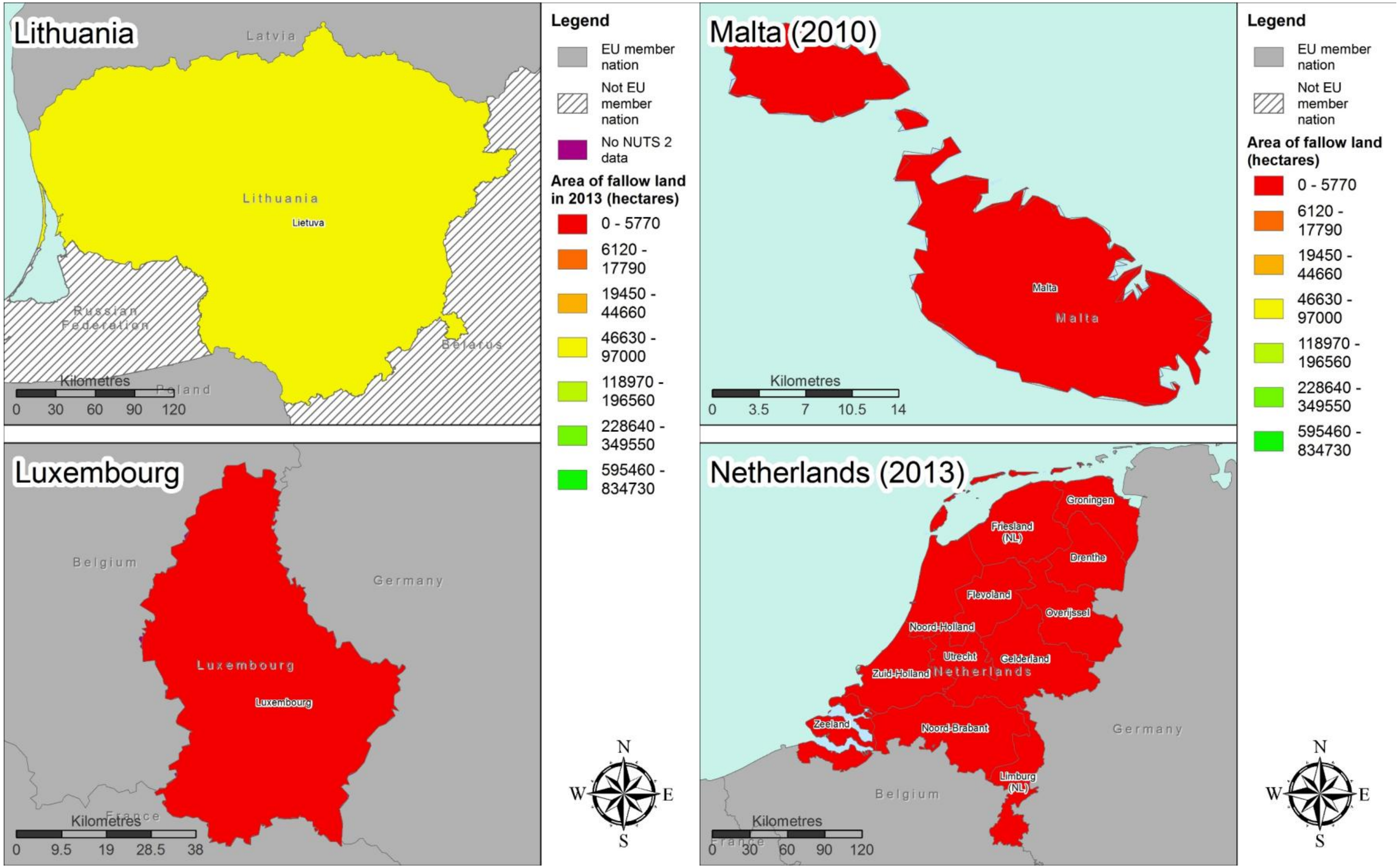


Figure 38. The distribution of fallow land for Poland, Portugal, Romania and Slovakia for the year 2013. Data are sourced from Eurostat.

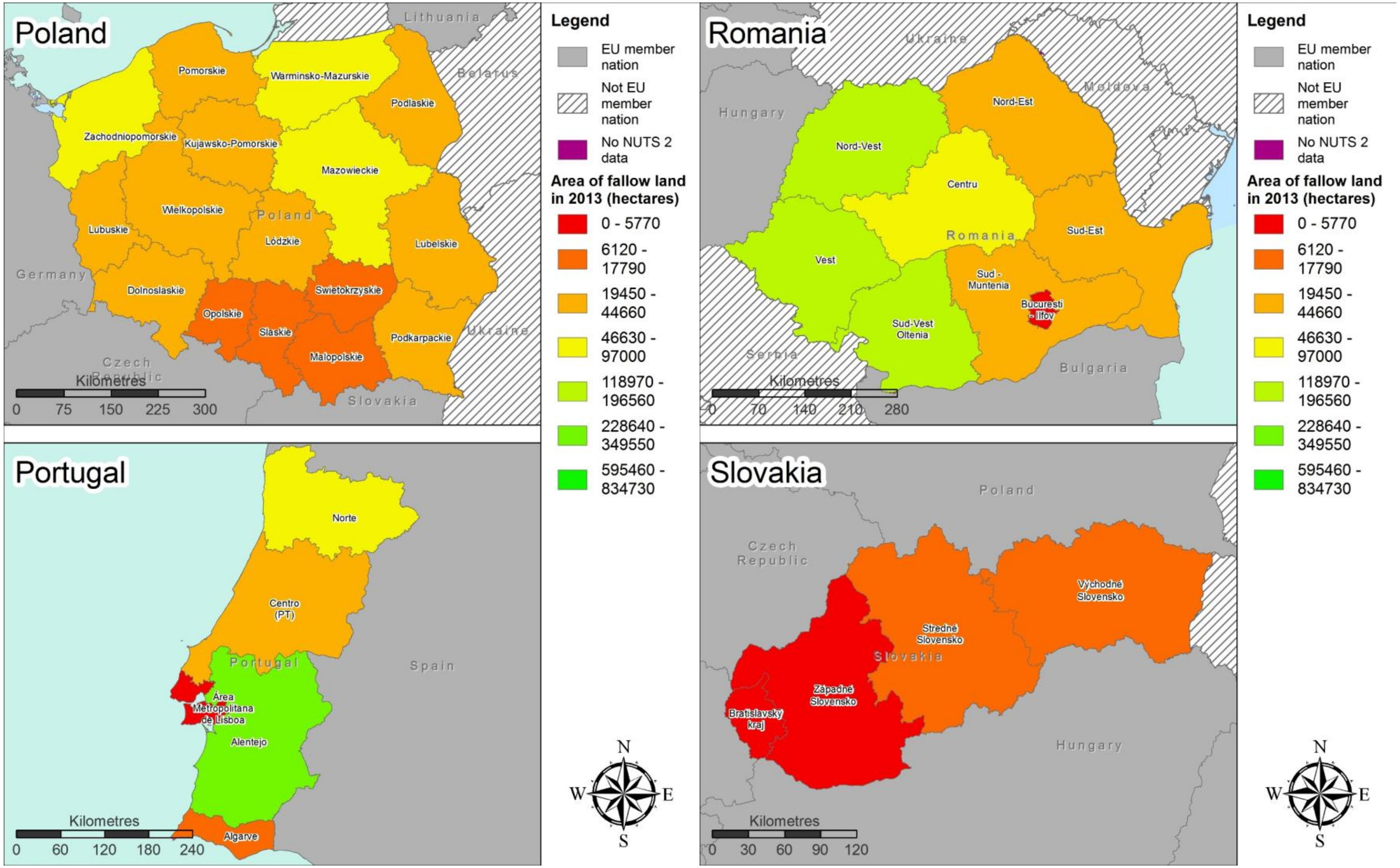
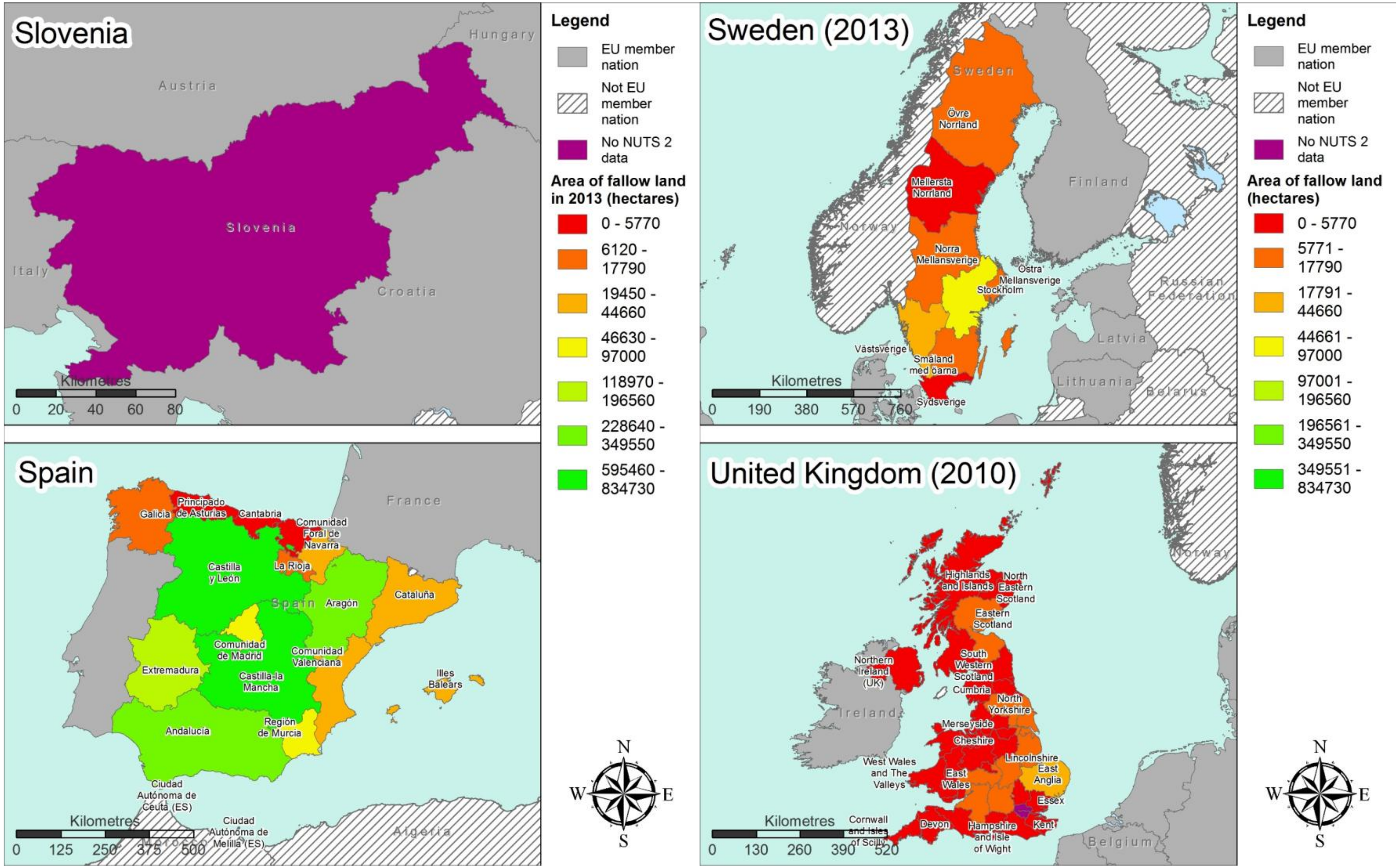


Figure 49. The distribution of fallow land for Slovenia, Spain and Sweden for the year 2013 as well as the United Kingdom for the year 2010. Data are sourced from Eurostat.



Annex B Barley production within the EU

Barley is an arable crop that is grown throughout the EU. It is not a crop of direct relevance to the assessments of low LUC land availability made in this report, it has however been shown to be a very useful surrogate or indicator crop that can be used to estimate potential camelina production volumes elsewhere (as presented in section 7 of this report). For this reason, an analysis of EU barley production by land area and crop yield is included here as supporting information.

Two datasets are available from Eurostat for land area dedicated to Barley in the EU. Unfortunately, the two dataset differ in temporal resolution, numerical precision and also disagree marginally on figures. The first dataset are available for the area of farmland dedicated to barley within the EU-28 all years from 1975 to 2014. The second dataset is available for the years 2005, 2007, 2010 and 2013. As the latter covers the same years as other dataset, has better numerical precision than the former and better coverage of nuts 2 regions, this dataset is presented here. A total of 14.0 million hectares were recorded as dedicated to barley production in 2005, 14.1 million in 2007, 12.4 million in 2010 and 9.3 million in 2013. Data deficiencies are present within the data as some NUTS 2 regions are not reported, meaning that these figures are likely to be higher in reality. In addition, only 20 nations are reported for 2013, creating an artificially low figure for that year. Individual total areas of barley land per EU-28 country for the years 2005, 2007, 2010 and 2013 are presented in Figure 50 through to Figure 53. All current member countries are represented for the years 2007 and 2010, however data for Croatia is missing in 2005 (possible due to the fact that it did not achieve member status until 2013). There are considerable gaps in the data for 2013, with only 20 members represented in the data. The reason for this is not known.

Four countries (Spain, Germany, France and Poland) were recorded as having greater than 1 million hectares of land dedicated to barley production in 2005 and 2007, however Poland fell below 1 million hectares in 2010 and 2013. Spain was consistently the nation with the greatest area of land dedicated to barley production across all four years.

Figure 50. The area of land dedicated to barley farming in 2005. Countries that were EU-28 members in January 2015 are displayed. Countries that are data deficient for 2005 are not displayed. Data are sourced from Eurostat.

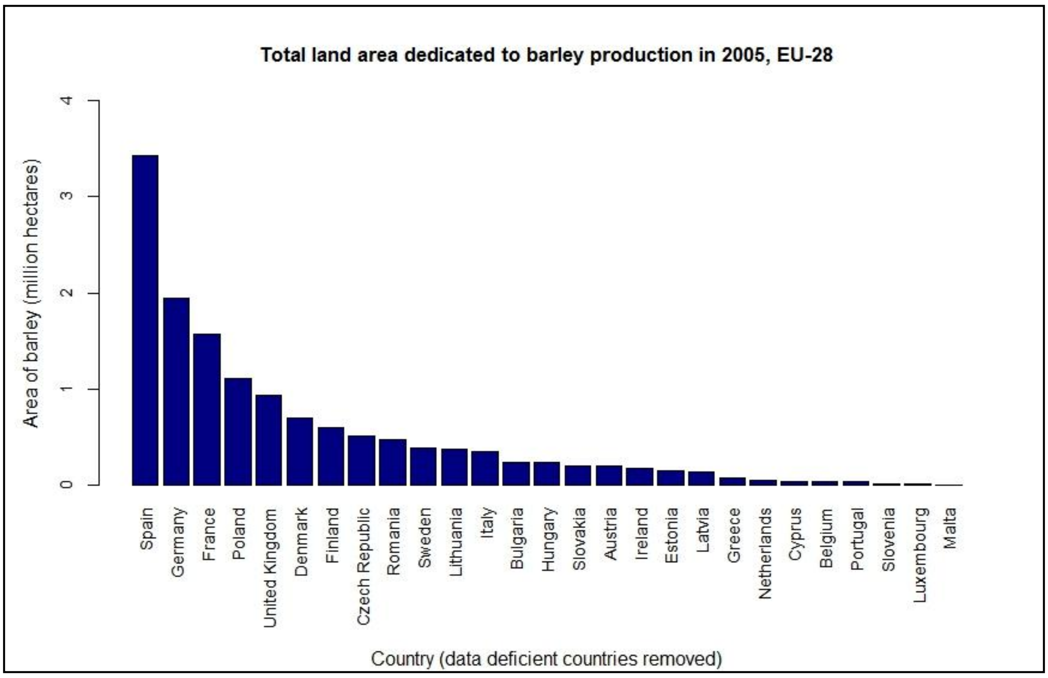


Figure 51. The area of land dedicated to barley farming in 2007. Countries that were EU-28 members in January 2015 are displayed. Data are sourced from Eurostat.

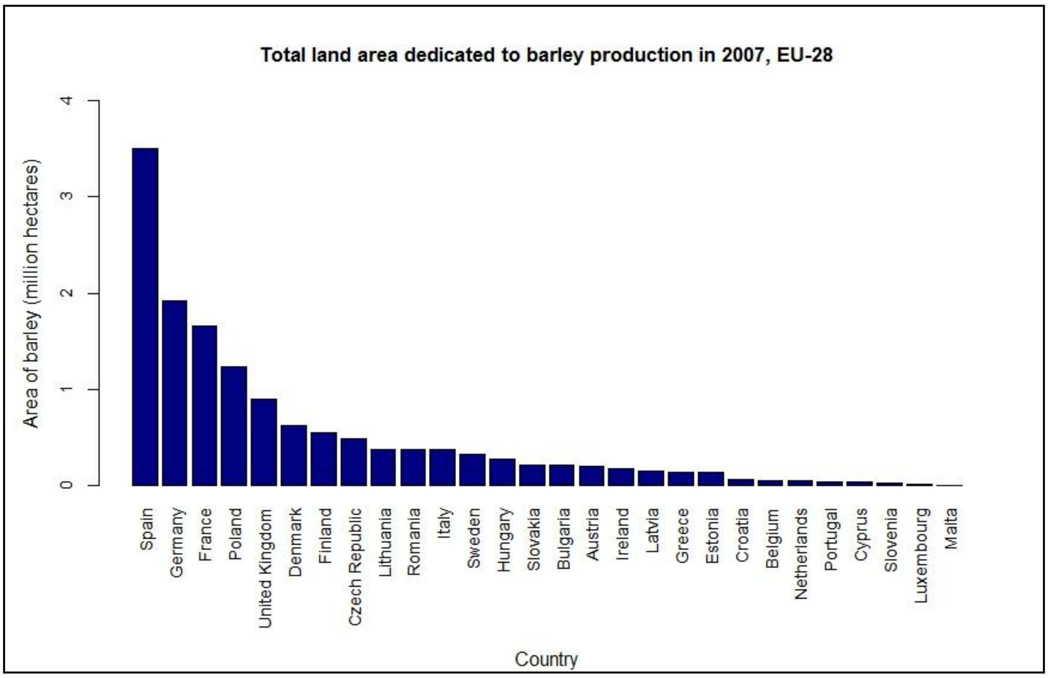


Figure 52. The area of land dedicated to barley farming in 2010. Countries that were EU-28 members in January 2015 are displayed. Data are sourced from Eurostat.

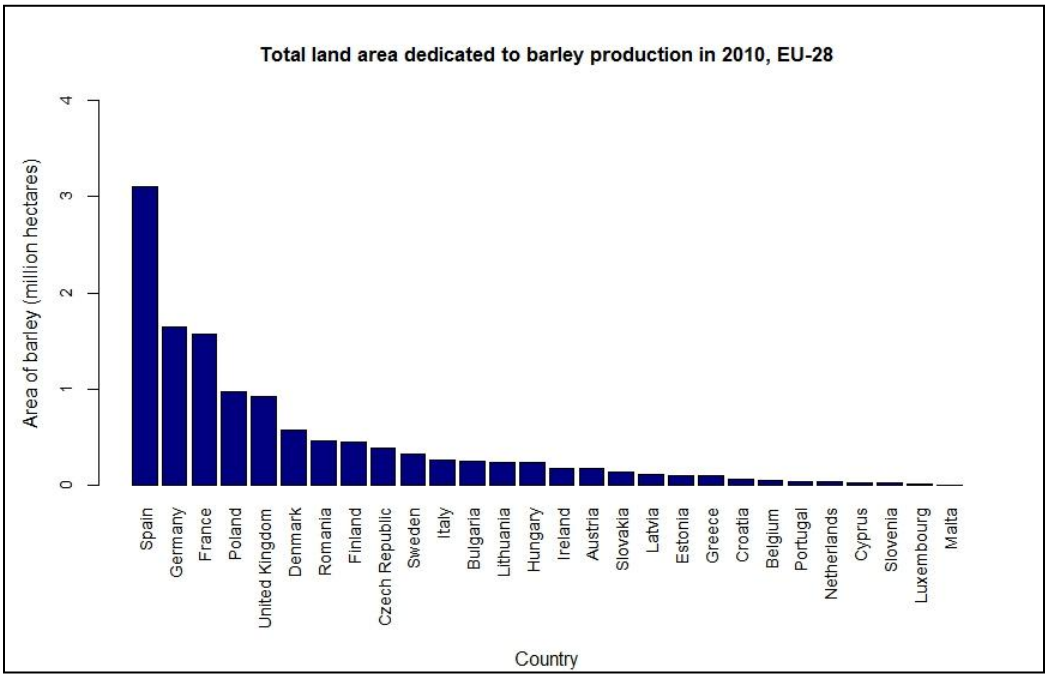
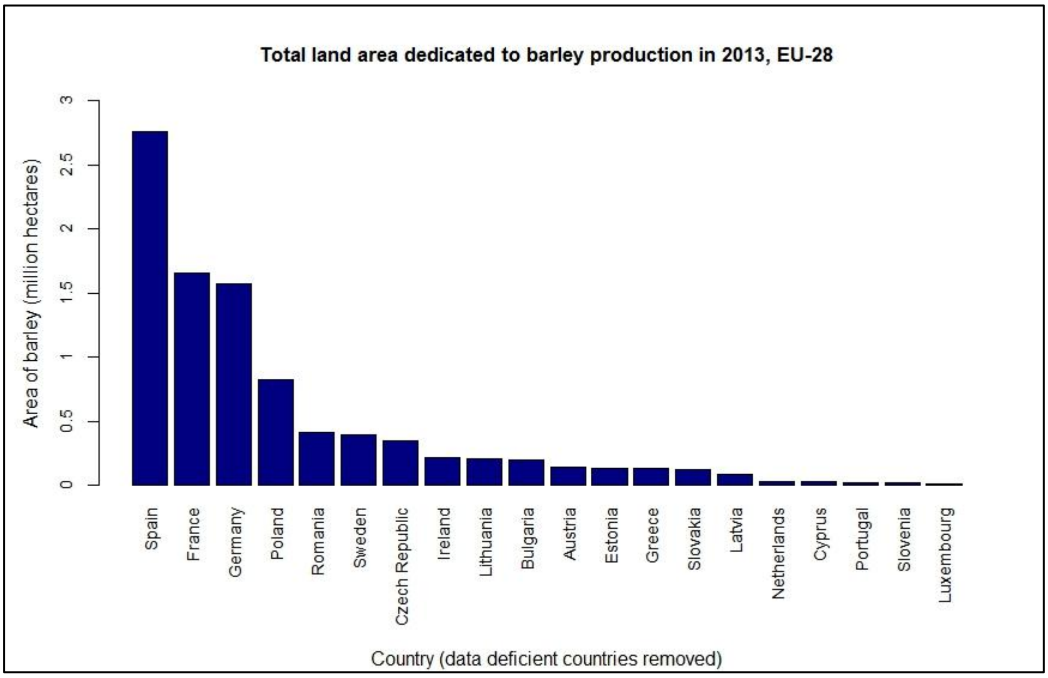


Figure 53. The area of land dedicated to barley farming in 2013. Countries that were EU-28 members in January 2015 are displayed. Countries that are data deficient for 2005 are not displayed. Data are sourced from Eurostat.



EU-28 member states with greater than 1 million hectares dedicated to barley

Three nations (Spain, France and Germany) were recorded as having greater than 1 million hectares of land dedicated to barley production in 2013. Of the EU-28, Spain had a considerably larger area of barley than any other nation at 2.8 million hectares. Although still significantly higher than other nations, this 2013 figure for Spain was lower than in previous years (in 2005, 2007 and 2010 the area of barley in Spain was consistently over 3 million hectares). The general distributional pattern of land dedicated to barley amongst NUTS 2 regions within Spain was consistent with the number of farms by NUTS 2 region. The central regions of Castilla y León and Castilla-la Mancha had the largest areas of barley with around 850,000 hectares each. As Castilla y León is the largest of all NUTS 2 regions in Spain, it may appear that the area of barley is simply a function of total area of the region. This perceived pattern is nullified however by Andalúcia, the second largest region in Spain yet dedicating around118,000 acres of land to barley production (14% of that in Castilla-la Mancha, the third largest region). The northern region of Principado de Asturias and the small north African NUTS 2 regions of Ciudad Autónoma de Melilla and Ciudad Autónoma de Ceuta had no land dedicated to barley production in 2013.

France had the second largest area of land dedicated to barley production in 2013, with a total of 1.8 million hectares. The NUTS 2 regions with the largest area of land dedicated to barley were Centre and Champagne-Ardenne with approximately 270,000 and 260,000 hectares respectively. No regions within mainland France were recorded as having zero land dedicated to barley in 2013, however the French overseas territories of Guadeloupe, Martinique, Réunion and Guyanne were all recorded as having a barley area of zero.

The country with the third largest area of land dedicated to barley farming in 2013 was Germany. NUTS 2 data were not available for Germany, and as such the data are presented within this report at NUTS 1 resolution. Bayern was the NUTS 2 region with the largest area of barley at around 350,000 hectares. This may be unsurprising considering that it is also the largest NUTS 1 region in

Germany by area (almost 100% bigger than Niedersachsen, the second largest NUTS 1 region). Berlin was the only NUTS 1 region recorded as having zero hectares of land dedicated to barley farming. However, the small regions of Bremen and Hamburg had very little land used for barley farming, with 170 hectares and 520 hectares respectively.

Total barley yields by EU-28 country and NUTS-2 regions for 2013

Yields of 5 tonnes per hectare and 8 tonnes per hectare have been discussed as critical upper limits for barley yield in relation to this project. As a nation, Belgium is the most productive of the EU-28 in terms of barley yield with 8.33 t/ha in 2013. This is the only nation with a yield of over 8 t/ha. A total of eight countries have a yield of between 5 and 8 tonnes per hectare, these are Ireland, the Netherlands, Germany, France, the United Kingdom, Denmark, Luxembourg and Austria. All other nations fall below the 5 t/ha threshold (except Malta where data are not available). These data are displayed Figure 54. Within country variance exists at the NUTS-2 level, which is displayed in Figure 55.

Figure 54. Total barley productivity yields (tonnes/ha) within the EU-28 at country level resolution for year 2013. Critical values are highlighted at 5 t/ha and 8 t/ha. Data sourced from Eurostat.

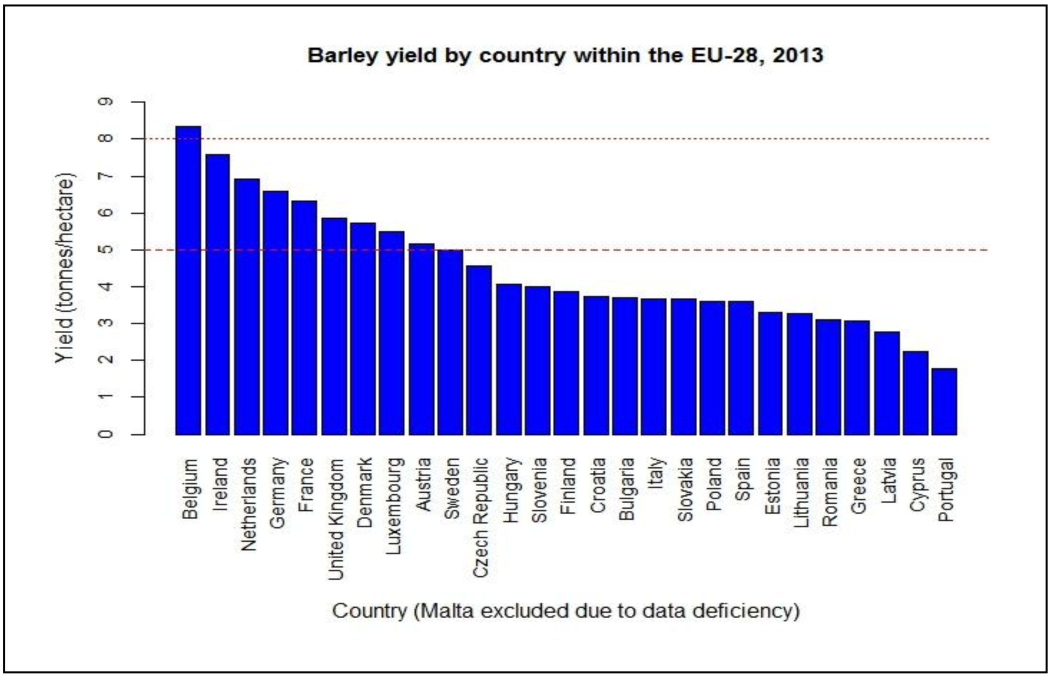
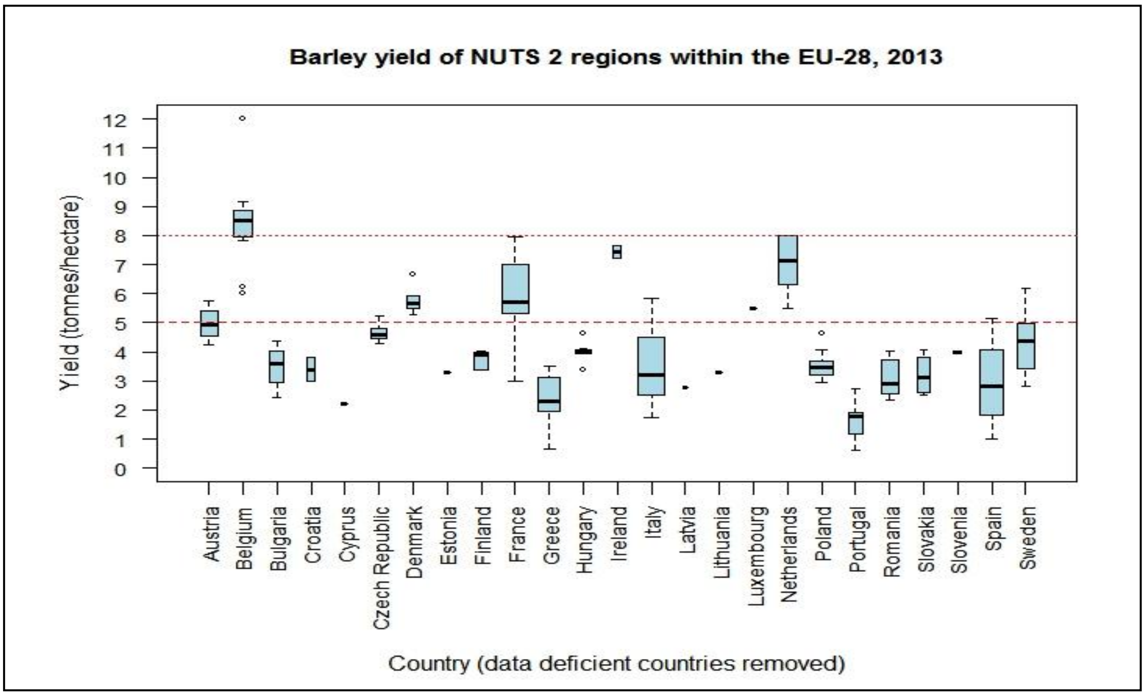


Figure 55. Barley yields (tonnes/ha) within NUTS-2 regions grouped by EU-28 nation for the year 2013. Median, upper quartile and lower quartile figures are represented by the box. Outliers (± 1.5x interquartile range) are displayed as points. The width of the boxes are proportional to the sample size (i.e. the number of NUTS-2 regions represented by the data). Critical values are highlighted at 5 t/ha and 8 t/ha. Data sourced from Eurostat.



Annex C Policy targets for management of local soil contamination

No European policy targets for the management of local soil contamination have been established, but national targets do exist in many EU member states. The following information is reproduced from EIONET 2011.

Country	Year	Political or technical target
Austria	2025	Identification of Contaminated Sites completed
	2030-2040	Essential part of the Contaminated Sites problem should be managed
	2050	Remediation and re-integration of identified Contaminated Sites into economic and natural cycle
Belgium (Flanders)	2036	Remediation started on sites with potentially contaminating activities and/or that are considered to be contaminated
Croatia	2025	Remediation of «hot spots», locations in the environment which are highly burdened with waste
Czech Rep.	2040	Political/technical level [government decree]: Environmental remediation of uranium and coal facilities DIAMO
Denmark	2016	Site identifications and preliminary investigations are completed nationwide
Estonia	2030	All contaminated areas to be remediated or sustained
FYR of Macedonia	2008-2014	Implementation of the closure/remediation measures for the top three hotspots from the annex 1
Hungary	2050	Handling of all historic Contaminated Sites. The Gov. Decision No. 2205/1996. (VIII.24.) adopted the National Environmental Remediation Programme (OKKP), which has three stages: short, medium and long.
Kosovo	2018	Drafting of land cadastre and developing monitoring system
	2025	Re-cultivation and adequate use of agricultural land
Montenegro	2008-2012	Recovery and/or closure of existing dumpsites, remediation of hot-spots (Contaminated Sites), construction of regional sanitary landfills
Netherlands	2015	Bringing risk at sites to an acceptable level for the current land use Handling of sites at risk with current land use
Norway	2012	Handling of (approx. 250) sites completed, where pollution is shown to be most serious, i.e. where pollution is released to priority areas or can pose a human health risk.
Romania	2020	Environmental remediation of the majority polluted areas
Serbia	2014	Priority list for remediation will be established.
	2019	20% of priority sites should be remediated.
Slovakia	2015	Remediation of the Contaminated Sites with the highest risk to human health and environment (to reach «good status of water» with respect to the Water Framework Directive)
Sweden	2050	Environmental objective: a non-toxic environment Remediation of priority sites by 2010 Other Contaminated Sites contained or remediated by 2050 at the latest
Switzerland	2025	Remediation or containment of historic soil contamination

Annex D PET parameterization

The parameterization of the Thornthwaite and Hargreaves PET estimation methodologies in shown below. These parameterizations are included to highlight the significant difference in the approach for the estimation of PET (and consequently aridity index). These differences are important since bioclimatic zones are defined from the value of the aridity index, typically: Arid (0 < AI < 0.2); Semi-arid (0.2 < AI < 0.5); Sub-humid (0,5 < AI < 0.75); and Humid (AI > 0.75).

9.1.1.1 Thornthwaite PET parameterization (1948):

PET = 16.0 * (L / 12) (N / 30) (10 Ta / I)α

where

PET is the estimated potential evaporation (mm/month),

Ta is the average daily temperature (oC) of the month being calculated (if negative use 0oC),

N is the number of days in the month being calculated,

L is the average day length (hours) of the month being calculated,

α = (6.75 × 10−7)*I3 − (7.71 × 10−5)*I2 + (1.792 × 10−2)*I + 0.49239

I = Σi=1 to 12 (Ti/5)1.514 is a heat index which depends on the 12 monthly mean temperatures Ta

9.1.1.2 Hargreaves PET parameterization (1985):

PET = 0.0023 * (Tmax – Tmin)0.5 (T mean +17.8) Ra

where

PET has units mm/day,

T is temperature (oC), maximum daily, minimum daily, and mean daily,

Ra is extraterrestrial radiation (mm/day).

[end of document]